

Governance of Metals Flows from Waste Electrical and Electronic Equipment in the Netherlands





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Governance of Metals Flows from Electrical and Electronic Equipment Waste in the Netherlands

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Sincerely,

MSc Violeta Paginu

SUMMARY

Electrical and Electronic Equipment (EEE) is essential for the development of economic activities, services and infrastructure that support our daily life. Driven by market expansion but also consumer preferences towards new sophisticated EEE, waste electrical and electronic equipment (WEEE) became the fastest growing waste stream in the EU. Various developments have been undertaken towards managing the WEEE flow in a sound and preventive manner on EU level. Nonetheless, WEEE remains a waste problem and is unjustly regarded solely as a "waste management problem" whereas the value of the stream represented by an ever increasing diversity of economical important metals is insufficiently addressed.

The main objective of this research is to asses the provisions of current EU policies and market incentives governing the WEEE sector with respect to economical important metals recovery and recycling. Interviews with actors from the EEE industry, WEEE sector as well as national authorise and academia have been conducted additionally to literature analysis as the main sources of primary and secondary data. The Industrial Ecology Concept and the Ecological Modernisation Theory served as the theoretical concept of this research. The research identifies that economical important metals are essential ingredients for EEEE manufacture and are subject to several life cycle bottlenecks that impede metals sound management. Among this are metals application, EEE product design and WEEE collection. These, together with a range of geo-political and economical issues contribute to low recovery and recycling rate of economical important metals from WEEE. The WEEE Directive provisions on WEEE collection, recovery and recycling targets have been identified to be to a certain extent counterproductive for efficient recovery and reuse of economical important metals from WEEE. As such there are market incentives to work upon only a few economical important metals which have high economical value. It is concluded that the WEEE Directive together with the Eco-Design Directive could support and create a regulative environment for future sound life cycle management of economical important metals. Thorough design and implementation of market based policy instruments to address both the companies and individuals' behaviour towards the environment as well as the environment as the main beneficiary have been identified as essential for future efficient and integrated metals management.

It is envisioned that future governing environment on metals flows will embody a mix of policies and market based instruments applied in a cooperative environment. More studies need to be done to answer such questions as whether the economical important metals need to be regulated as such on the first place and which regulation or mix of instruments is the most suitable for this purpose.

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List of Abbreviations

BFRs Brominated Flame Retardants

CS Compliance Scheme

DfE (DfD) Design for environment (Design for Dissasembly)

EC European Commission

EEE Electrical and Electronic Equipment
EMT Ecological Modernization Theory

EU European Union

HPFS Hewlett-Packard Financial Services

IEC Industrial Ecology Concept

ICT MILIEU The Dutch Foundation for the Disposal of ICT Equipment

IHSPE Inspectorate of Housing, Spatial Planning and the Environment

MI&E Ministry of Infrastructure and the Environment

MWYs Municipal Waste Yards

OVAM Public Waste Agency for Flanders

TU Berlin University of Technology, Berlin

TU Delft Technical University, Delft

UNESCO-IHE UNESCO IHE Institute for Water Education

UNU United Nations University

WECYCLE (NVMP) The Dutch Foundation for the Disposal of Metal and Electrical Products

WEEE Waste Electrical and Electronic Equipment

Economical important metals and their chemical symbols

SbAntimonyBeBerylliumCoCobaltGaGalliumGeGermaniumInIndiumNbNiobium

PGMs¹ Platinum group metals REMs² Rare earth metals

TaTantalumWTungsten

¹ The PGMs consists of ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir) and platinum (Pt);

² The REMs consists of 15 lanthanoids plus scandium and yttrium.

Definitions

- Electrical and electronic equipment or "EEE": equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields falling under the categories set out in Annex IA and designed for use with a voltage rating not exceeding 1000 Volt for alternating current and 1 500 Volt for direct current (Directive 2002/96/EC);
- Waste electrical and electronic equipment or "WEEE": electrical or electronic equipment which
 is waste within the meaning of Article 1(a) of Directive 75/442/EEC, including all
 components, subassemblies and consumables which are part of the product at the time of
 discarding (Directive 2002/96/EC);
- *Prevention:* aimed at reducing the quantity and the harmfulness to the environment of WEEE and materials and substances contained therein (Directive 2002/96/EC);
- Reuse: any operation by which WEEE or its components are used for the same purpose for which they were conceived, including the continued use of the equipment or components which are returned to collection points, distributors, recyclers or manufacturers (Directive 2002/96/EC);
- *Recycling:* the reprocessing in a production process of the waste materials for the original purpose or for other purposes (but excluding energy recovery) (Directive 2002/96/EC);
- Producer: any person who, irrespective of the selling technique used manufactures and sells
 electrical and electronic equipment under his own brand; resells under his own brand
 equipment produced by other suppliers; imports or exports electrical and electronic
 equipment on a professional basis into a Member State (Directive 2002/96/EC);
- Extended Producer Responsibility: producers' acceptance of returned products and of the
 waste that remains after those products have been used, as well as the subsequent
 management of the waste and financial responsibility for such activities (Directive
 2008/98/EC);
- Compliance Scheme: producers meeting their Extended Producer Responsibilities by setting up and operating individual and/or collective take-back systems for WEEE from private households (Directive 2002/96/EC)
- Eco design: the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle (Directive 2009/125/EC)

INTRODUCTION

1.1 Problem statement

Electrical and electronic equipment (EEE) is a product group characterized by extreme diversity and increasingly fast innovation cycles. Their production supports one of the fastest growing domains of manufacturing industry in the world. Favoured by market expansion but also consumer preferences towards new sophisticated EEE, waste electrical and electronic equipment (WEEE) became the fastest growing waste stream in the EU. Currently, EU 27 taken as a whole, generates each year between 8,3 to 9,1 million tonnes of WEEE and it is expected that this amount will grow to 12,3 million tonnes by 2020 (EC, 2008). By nature, WEEE is a very complex waste stream. It is composed of different materials such as ferrous and non ferrous metals that if recovered and recycled appropriately may compete in quality with virgin materials. There are also several hazardous substances such as CFC, heavy metals, etc., that if not treated appropriately will pose danger to environment and human health. Thus, appropriate management of WEEE is essential and important for economy, environment, sustainable resource management and human health (EC, 2010).

In order to ensure that WEEE is managed taken the above mentioned considerations, the EU has introduced the *Directive* 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE) along with Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment. These two which provide specific measures on WEEE management with the aim to prevent, reuse, recycle and other forms of recovery of such wastes so as to reduce the environmental impacts from these on EU scale. Within the WEEE Directive, central attention is given to the producer of EEE which, in accordance with the Extended Producer Responsibility principle, is administratively and financially responsible for the management of the EEE when these turn into the waste phase. Various developments have been undertaken towards managing WEEE flow in a sound and preventive manner on EU and national level. This includes the introduction of compliance schemes to organise collection and treatment of WEEE on behalf of producers, opening of recycling companies to perform recovery of materials, development of the recyclables market and public education campaigns to raise public awareness on the issue.

Nevertheless, studies from the field reveal that WEEE regulations and practices overall fail to address the WEEE flow on EU level effectively. This is due to the following aspects:

- WEEE flow: only 1/3 is officially collected and treated via designated compliance schemes;
- WEEE treatment: a large amount of WEEE undergoes substandard treatment, causing environmental and human risks but also a continuous loss of valuable resources;
- Administrative associated problems: the difference among the EU Member States in policies enforcement and EEE producers compliance, monitoring and reporting cause distortion of competition on the market and unnecessary administrative burden both for EEE producers as well as competent authorities;
- Comprehensive incorporation of sustainability concepts into EEE systems i.e. DfE, integrated materials management and C2C are still insufficiently implemented through current production and consumption systems.

Many of these problems originate from the fact that WEEE is unjustly regarded solely as a "waste management problem" and the value of the stream represented by an ever increasing amount and diversity of materials and resources is insufficiently addressed.

A modern electronic device such as a mobile phone may contain more than 40 chemical elements of the periodic table (Hagelüken, 2006) Among these are base metals such as copper (Cu), tin (Sn), aluminum (Al), iron (Fe), special metals such as cobalt (Co), indium (In), antimony (Sb) and precious metals such as silver (Ag), gold (Au) and palladium (Pd). Recently, a range of the metals applied in EEE gained increased attention. This is mainly due to metals unique physical and chemical properties which confirm high performance to the product, increased demand by a range of green applications such as photovoltaic panels, wind turbines, electrical cars but also a range of geo-political issues that question the metals secure supply in the future. Taking into consideration that EU is highly dependant on imports of metallic minerals, as its domestic production is limited to about 3% of world production, EU has developed a list of 14 economically important raw materials which are subject to high risk of supply interruption (EC, 2010). Among these materials are a range of metals which are largely used in EEE (ICT equipment) manufacture, such as antimony (Sb), cobalt (Co), gallium (Ga), germanium (Ge), indium (In), certain platinum group metals (PGMs), rare earth metals (REMs), tantalum (Ta) and tungsten (W).

WEEE represents a tremendous potential source of economical important metals which EU could benefit from.

Recovery of metals from WEEE may bring an array of economical, environmental and societal benefits. First of all, recycling and recovery of metals is beneficial to EU base of secondary materials, the economic development of recycling and other relevant industries as well as create employment for low skilled personnel. A diversity of environmental and societal benefits among which is conservation of land, less GHG emissions associated with virgin metal production, avoidance of associated mining production waste and waste water as well as impact on the local inhabitants, flora and fauna around the mining sites.

Despite all the efforts of the EU WEEE strategies to establish a circular flow economy that treats its resources wisely, currently a range of valuable materials (economical important metals) are still lost.

In order to achieve EU objectives towards a recycling society seeking to avoid waste and use it "as a resource" a range of legal, organizational, technological and educational issues should be reconsidered at the EU level. In this respect, the presence of supportive and sound strategies as well as of market incentives in achieving this sustainability transition is of particular interest and importance.

1.2 Research objective

Main objective

• Asses the provisions of current EU policies and market incentives governing the WEEE sector in respect to metals recovery and recycling

The research shall contribute to emerging knowledge on innovative waste-to-resource policies and management practices by providing better understanding of the current situation from the field of WEEE and particularly from the perspective of how policies & market instruments shape the relationship between

the metals recovery and recycling from WEEE – stakeholders involved - and available technologies of the WEEE system. These shall result in a range of recommendations applicable to the current EU strategies governing the WEEE sector, particularly in respect to sustainable and efficient metals recovery and recycling.

1.3 Research questions

- 1. What are the main bottlenecks in metals life cycle management and their relation with metals recovery and recycling from WEEE?
- 2. On the EU level, how effective are the WEEE regulations in promoting metals recovery and recycling?
- 3. Within EU, what market incentives in the area of WEEE exist in relation to recovered metals?
- 4. What interventions are needed in current EU strategies to improve the sustainability aspects of metals recovery and recycling from WEEE?

1.4 Research scope and limitations

Scope

EEE refers to a variety of products, beginning with large house hold appliances to medical devices. The present research is limited to IT, telecommunications and consumer equipment which in accordance with the Annex I A "Categories of electrical and electronic equipment", of the WEEE Directive corresponds to categories 3 and 4 respectively. These 2 categories have been selected because of the high economical important metal content which highlights the economical value of the equipment at the end-of-life stage as well as the range of hazardous substances which are embodied with these metals and need proper treatment.

As mentioned in the introduction section, modern IT equipment may contain a very large list of metals. In order to give focus, the present research will be developed around 3 metals which have been identified to have the most share application in IT sector, namely indium, gallium and ruthenium. The metals will be assessed from the perspective of flows through production and consumption systems, current technologies and actors involved in metals management. This will be supplemented by the analysis of the current policies and strategies governing the WEEE sector which have been adopted at European Union (EU) level and their implementation at nation level. The availability and the structure of market incentives will be investigated in respect to recovered metals and the influence of these incentives on development of innovative recycling practices will be investigated as well.

The country of focus of this research is the Netherlands. The description of the current situation, including WEEE management, stakeholders, policies and market incentives is therefore based on the state of affairs and arrangements characteristic for the Netherlands.

Limitations

Due to a working timeframe of 6 months, the study will be limited to certain boundary of primary sources of information and limited number of respondents. An important element will be the willingness of respondents to co-operate. Consumers, as an individual group of respondents will be addressed in this study only on general level. This will be done via the respondents listed in this study. This is due to the fact that, consumers as a respondent group is a large group which may need a different methodology of inquiry and data analysis.

1.5 Methodology

Research Design

The present research is designed as a *cross sectional study*. The aim of this is to explain and analyse the prevalence of a problem or attitude with respect to the research problem at the time of investigation through primary and secondary sources of information. From the time perspective, the research is a *retrospective-prospective* study. The main focus of this is current strategies as well as market structures that govern and influence the recovery and recycling of metals from WEEE. The prospective aspect will be introduced through the sustainable development concept. The current study is a *non-experimental study* as it looks to examine the legal and market grounds of metals recovery and recycling from WEEE and thus, no experiments will be conducted.

Method of data collection

Data are collected applying various methods and various primary and secondary sources. One of the methods applied is interviewing actors related to WEEE domain and the problem under investigation. This method is the most appropriate for complex situations such as governance of WEEE and is useful for obtaining in depth information as well as opinions and informal reflections. The method allows for the questions to be supplemented and explained in person. The instrument for data collection is Questionnaire with open-ended questions. This type of questions allow broad and in depth information to be discussed and reflected upon. The nature of questions included in the questionnaire is adjusted to the profile of the respondent: i.e. EEE producer, WEEE recycler, policy developers. The respondents are contacted by phone/email and meetings are organized to collect the data in person.

Literature review via both summarization and synthesis of the published information in the field of WEEE and documents analysis are the other 2 methods which are applied in the current research. Secondary sources of information served various reports from academia and private institutions, companies, scientific publications and articles as well as informative reports by the European Commission (EC) and other EU institutions available on the internet.

Sample

The sample consists of representatives of the EU and national authorities involved in policy development, as well as EEE producers, WEEE recyclers (metal refineries) and research institutes involved in WEEE and metals related issues. In total 15 interviews have been performed (see Annex 1 for the list of interviewed stakeholders).

Data analysis

Analysis of the questionnaire as well as of secondary information will be done taking into consideration the content of the obtained and identified information.

1.6 Structure of the report

The content of this thesis consists of six chapters, including the introduction chapter.

The Introduction chapter introduces the reader to the issues on metals and WEEE management and defines the problem under research. It precedes with the description of the research aim and research questions that serve as guideline throughout the thesis. The chapter also refers to the research scope and limitations. In this way the reader is acknowledged with the boundaries of the current study from the very beginning. Last, methodology is presented with particular attention given to the development of the instrument for primary data collection.

Chapter II introduces and elaborates on concepts and theories which served as conceptual framework to analyze the economical important metals problem and the WEEE management. The Industrial Ecology Concept has been selected as a concept to analyze the problem from the triangle model perspective, namely: metals flow, technologies and actors. Whereas the Ecological Modernization Theory guided on identification and development of the changes that are needed in the WEEE field to address the metals problem. The chapter concludes with the formulation of a vision for the WEEE sector which in general translates the prescription of the theories into the WEEE system in order to better understand and visualize the sustainability and integrated management of metals from WEEE.

Chapter III is an overview chapter presenting the current situation on economical important metals and WEEE management. The chapter is structured in three sections addressing the WEEE material composition, recycling and recovery technologies and stakeholders which are involved in WEEE system management. The first section presents a general overview on WEEE material composition and gives more details on 3 metals which are extensively applied in EEE manufacturing, namely indium, gallium and ruthenium. Metals are described against such criteria as metals global reserves and distribution, metal application, current and future demand, price as well as availability of substitutions and recycling technologies. The second section presents an overview on current recycling and recovery technologies. It describes the logistical steps end of life EEE passes from collection down to recovery and refinery. The section gives a generals description of the common recycling and metals refinery technologies. The third section explains the range of stakeholders which create the WEEE system and the responsibilities of these in managing the WEEE in line with both EU and national legislation. The chapter concludes with an overview on the WEEE legislative and institutional framework with the focus on the Netherlands.

Chapter IV, the Results Chapter presents the results of the interviews and literature overview with respect to economical important metals and WEEE management. The chapter is structured in 4 themes, namely WEEE Metals Flow, WEEE Metals Processing and Recovery Technologies, WEEE Actors and Networks and WEEE Governance. The first section applies a life cycle approach to describe the metals which are central to this study and reflects on metals identified bottlenecks. The second section presents the description of the WEEE recycling and recovery technologies including the identified technological restrictions which impede efficient treatment and recovery of

metals. The third section describes the WEEE system actors and the networks these have created. The section explains the activities of these networks and the driving forces behind these. The chapter concludes with the description of the current WEEE legislative frameworks both in the EU and in the Netherlands and the milestones of these in creating and supporting a sound environment for metals recovery and recycling.

Chapter V, Discussions Chapter discusses the results of the investigation in the light of the environmental theories prescriptions. The chapter is organised in 3 themes, namely: Complexities in closing metal loops, Technologies innovation and integration as a key to WEEE Reform and From National towards Metals Flows Global Governance. Under the first theme, the results of the investigation are compared with the provisions of the IEC in closing the metal loops. It is argued that the current tools of the IEC to assess the bottlenecks in metal life cycle need to be reconsidered. Structural economics tools based on dynamic input-output calculations may be appropriate. Under the second theme, the state of current technologies is compared against the provisions of the EMT. It is argued that current WEEE technologies are applied as individual artefacts and that these need to transit toward integration, to be applied for their functionality. The service economy with the product service system is proposed as a model where technologies are integrated and materials input into economies is decoupled from environment in line with the Dematerialisation principle of the IEC. The third theme discusses on the nature of governance applicable to metals flows. It is argued that the sociology of networks and flows theory could serve as a more appropriate theory for the development of future governing principles applicable to economical important metals.

The Conclusions, Chapter VI, concludes on the research via the research questions. It summarises the major bottlenecks which have been identified during metal life cycle management. It concludes the efficiency of current legislation from the WEEE field with respect to recovery and recycling of metals. It lists the range of market incentive to perform the recovery and recycling of metals from WEEE. Finally, it summarises the array of interventions which are needed in the current governing system to achieve an integrated and sound management of metals from WEEE.

Recommendations chapter, chapter VII, proposes several recommendations to bridge better the electronics and WEEE sector activities. This is done with the purpose to ultimately provide for a framework where metals are managed integrally and efficiently through entire life cycle. The recommendations are structured according to the group of actors these are to be addressed, namely: EU and national authorities, industries, academia and society at all.

II CONCEPTUAL FRAMEWORK

The current study is based on two theoretical frameworks: the Industrial Ecology Concept and the Ecological Modernization Theory. Together they will provide for the analysis of the current situation concerning the recovery and recycling of metals from WEEE as well as provide background for the identification of bottlenecks in metals governance.

2.1 The Industrial Ecology Concept

The ideas behind the Industrial Ecology Concept (IEC) are considered to be present and implemented for over more than 30 years. System ecologists studying biochemical cycles had already an understanding of the industrial systems as subsystem of the biosphere. One of the earliest occurrences of the expression of "Industrial Ecosystem" which is in line with the current interpretation of the concept can be found in a paper by the well known American geochemist, Preston Cloud (Erkman, 1997). This paper was first presented in 1997, during the Annual Meeting of the German Geological Association. The paper highlighted the importance of matter and material flows in the human economies in a thermodynamic perspective and the importance of technological dynamics in relation to these flows. Cloud was not alone, and there are records that confirm that the ideas were followed by several other members of academia who introduced the notion of industrial ecology in university curricula (Hall and Vigneron in Erkman, 1997).

Nevertheless, a significant contribution to the formation of the concept of industrial ecology was realised via an article published in 1989 in the monthly magazine Scientific American by Robert Frosh (Frosch and Gallopoulos,1989). In this publication, Frosh together with Nicholas E. Gallopoulos acknowledge the traditional model of industrial activity in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed. They suggest that these processes should be transformed into a more integrated model: a model which found its name in industrial ecosystem. In such a model the consumption of energy and materials is optimised, waste generation is minimized and the effluents of one process serve as the raw material for another process (Gallopoulos, 2006). However, Frosh was rather critical and acknowledged the difficulties industries may step into towards interpreting this biological resemblance. He suggests that to diminish these difficulties, not only industries will have to perform changes in their production systems but also governments and consumers are to perform behavioural changes. In general, the article was written in a very elaborative way, providing good examples from the plastics, iron and the platinum group metals industries in creation of sustainable industrial systems. It also presented the gains of implementing the IEC and prominent examples that are needed for system optimisation. These are referred to latter in the core elements of the IEC. Along the same lines were the activities of Nelson Nemerow who has been active in waste treatment technologies. He envisioned industrial systems as environmentally balanced complexes, which contribute to the emergence of the "zero pollution" model (Nemerow and Dasgupta, 1982).

Therefore, it can be concluded that the IEC emerged in the 70's. It has been elaborated on during the late 80's and by the end of the 90's an acknowledgment was reached among many institutions belonging to different countries all over the world. It was at that stage, after the publication of the Frosh and Gallopoulos that the concept infiltrated into government, engineering and business circles. There was an increased search for new strategies of development, new notions, and new perspective in which environment had its own independent role. More recent contributions to the concept development and maturation can be attributed to Braden Allenby, who presented the first doctoral dissertation on industrial ecology (Allenby, 2000), Ernest Lowe linked the environmental

management with the principles underlying the IEC (Lowe and Evans, 1995) and particularly Hardin Tibbs who introduced the concept as "a new environmental agenda for industries" (Tibbs, 1991).

The example of Japan, as an earliest adopter of the IEC, served as a guideline in development of environmental policies and management programs, is of particular relevance in this context (Koppen, 2002). The Japanese authorities explored the concept in order to identify possibilities to orient their economy towards activities that would consume less material and would instead be based on information and knowledge. It was at that time when it was decided to consider the economic activities in an ecological context with particular attention on material and energy aspects. Therefore, renewable energy projects and energy efficiency projects were already launched in Japan in the middle of the 70's. Japan can also be delimited as a country where besides long-term strategic vision and systematic approach on economical development in line with the IEC concept, these developments were applied on a large scale. Among these was the introduction of advanced technology which largely improved the materials consumption. The main conclusion that can be derived form this example is that Japan was first to understand the benefits of the IEC and it succeeded well in implementing the concept. This was due to two pillars: the vision which served as a road map towards sound economical development and the technology dynamics which with continuous research to provide for continuous improvement in efficiency and beyond this.

The IEC concept studies the materials and energy flow through an industrial system. From their initial extraction to their inevitable reintegration into biogeochemical cycles, the industrial system interaction with the biosphere with the scope to elaborate on strategies, tools and techniques to lead industrial and ecological systems into a balance state (Erkman, 2001).

The study of the industrial system, which can be analysed through an application of the materials-balance principle, is attributed the term "industrial metabolism" which is an integral part of the IEC. The concept is a new approach to industrial design of products and processes and the implementation of sustainable manufacturing strategies. This is a new interpretation of the industrial systems and is seen as an integral part of the surrounding natural and artificial systems. It is about optimising the total materials cycles from virgin materials extraction to component, product, waste and ultimately disposal (Jelinski et al., 1992, Frosch, 1995).

Further, the core elements of the IEC which are helpful to understand the IEC concept are presented in more details.

The biological analogy

The IEC extensively talks and refers on the fact that industrial systems may be viewed similar to biological systems. Only by resembling to the latter development can it be maintained in both developed and developing countries without causing sever adverse affects on the environment (Isenmann, 2003a) (Isenmann, 2003b). The resemblance as well as the relationship between the two systems is prominently discussed by Frosch and Gallopolus:

"In a biological ecosystem, some of the organisms use sunlight, water, and minerals to grow, while others consume the first, alive or dead, along with minerals and gases, and produce wastes of their own. These wastes are in turn food for other organisms, some of which may convert the wastes into the minerals used by the primary producers, and some of which consume each other in a complex network of processes in which everything produced is used by some organisms for its own metabolism. Similarly, in the industrial ecosystem, each process and network of processes must be viewed as a dependent and interrelated part of a

larger whole. The analogy between the industrial ecosystem concept and the biological ecosystem is not perfect, but much could be gained if the industrial system were to mimic the best features of the biological analogue" (retrieved from Jelinski, 1992).

In order to better understand the rationale between the two systems and the need for resemblance, it is constructive to think of the evolution of biological systems. Jelinski describes the evolution of the earliest life forms on earth through the materials cycles (Jelinski, 1992). At the very beginning there were large resources and few life forms, thus the impact on the resources amount was insignificant and the fact the materials flowed only in one direction, in linear flow, had no negative influence on the resource base (type I). Second, when number of life forms increased and the resources became proximal, the resulting life forms became strongly interlinked with each other. This led to the creation of different networks which are known today as biological communities. Despite the fact that there are less resources flowing in and less waste is generated, due to the activities of these biological communities, such system is still unsustainable as resource amounts are constantly decreasing (type II). The scholar concludes that these communities, in order to sustain over time, or in contemporary terms to be ultimately sustainable, evolved to be completely cyclical in nature. Here "resources" and "waste" are undefined "since waste to one component of the system represents a resource to another" (type III). Therefore, the ideal use of resources and materials in industrial systems, in sustainability terms would be a model as described above, a model where "resources=waste", thus type III. Assessing the development of the industrial systems it can be stated that currently the prevailing forms of industrial processes resemble model II. There is a large degree of difference in developed countries which strive towards type III and developing countries where type I still prevails. The reasons behind the industrial system evolution are various regulations (pollution control regulations), economic incentives (recovery of materials which are valuable i.e. precious metals), but also the fact that industrial systems become larger to meet the ever increasing consumption demands, whereas the amount and availability of materials depletes or becomes a shortage.

Concluding, the IEC looks at the materials flow through four central nodes: the materials extractors, the materials processor or manufactures, the consumer and the waste processor (Figure 1 derived from Jelinski, 1992). Materials cyclical flow within the nodes and the system level among the nodes may lead to a system which is more efficient in managing its resources. Furthermore it has less impact on the external supporting natural systems and it is more likely to sustain and develop in long term perspective.

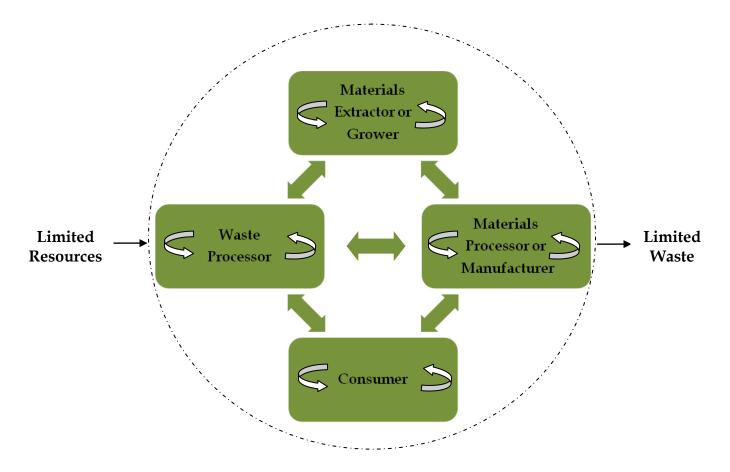


Figure 1: An interpretation of the type III model applicable to an industrial ecosystem Source Jelinski, 1992

The use of system perspective

As mentioned above the IEC views the industrial system as integral part and strongly interconnected with other natural and artificial systems. The concept emphasises the need for a system approach when assessing the system. It is suggested to take into consideration the relation and interconnections of the system with surroundings in order to prevent the environmental problem being moved into a different system or into another media. In applying this approach, the IEC uses the following tools: Materials Flow Analysis, Mass Balance Calculations, Life Cycle Analysis, System Modelling Tools, interdisciplinary studies, etc.

Applied at the material/substance or product level, these tools can provide constructive information concerning the flows, impacts and sinks. For instance Material Flow Analysis captures and describes the entire material flow of inflows such as raw materials and fuels and outflows such as products, flue gases and solid wastes, associated with a specific system boundary (Hinterberger et al., 1997). Based on this data, environmental impacts associated with these flows can be delimited. Material Flow Accounting (MFA) refers to a number of methodologies which can be used to provide information on industrial metabolism. MFA refers to accounts in physical units comprising the extraction, production, transformation, consumption, recycling, and disposal of materials, usually in terms of kilograms. MFA can be carried out on different levels, ranging from international, national and regional scales, down to the community or company level. MFA based analyses include approaches such as substance flow analysis, product flow accounts, material balancing, and bulk material flow accounts. Substance Flow Analyses trace the flow of selected chemical substances or compounds through the society. Product flow accounts trace the flow of

certain products or product groups through the economic system. These and a range of other modern tools, which emphasis is more on financial aspects, are particularly applied in research and as supporting tools for policy development. Product Chain Analysis, Integrated Product Policy, Extended Producer Responsibility are all examples of policy instruments where these tools are extensively applied. The aim is to reduce the environmental impact of the product/substance during various stages, beginning with the cradle down to the grave.

The role of technological change

Technology and particularly technological innovation is one of the themes that are central in the IEC. Although much is debated among scholars, the prevailing opinion is that technological change can bring solutions to many of the current complex environmental problems (Graedel, 2000) (Thomas et al., 2003). Eco-design via technological application is one of the examples where products are designed with modified or new characteristics. This is done in order to minimize the environmental impact of the product during the whole product life cycle. Electronics industry is one good example where various changes have been introduced at the product level in order to minimize the product impact on the environment. Among these are applications of joining technologies instead of adhesives such as snaps, darts and screws that allow for easy disassembling of products. This also contributes to minimization of the variety of materials used, marking of components clearly with plastic type identifiers, replacement of hazardous materials, etc.

Secondly, technological innovation is mostly seen to be in the domain of entrepreneurs, who have good knowledge of industrial processes and are generally interested in clean and innovative technologies. Due to high performance, material, energy use, generated emissions, these can gain competitive advantage on the market. Socolow goes beyond these and refers entrepreneurs as "policy-makers rather then policy takers" by highlighting the activity of a range of entrepreneurs who promote beyond compliance environmental strategy and behaviour (Socolw, 1994).

Dematerialisation and Eco-efficiency

Dematerialization, material productivity, decarbonisation and eco-efficiency are all integral parts of the IEC. Overall the IEC endorses processes and products, which are sounder in respect to the environment and score better in respect to performance and materials and energy use. For instance dematerialisation is a term which implies "reduction of the materials use to produce an economic output, to decouple the environmental impact from the economic growth" (Cleveland and Ruth, 1998). Another example which can be attributed to company and process level is the term "eco-efficiency". Ecoefficiency is defined as the process to deliver competitively priced goods and services that satisfy human needs and brings quality of life while progressively reducing ecological impacts and resources intensity throughout the life cycle to a level at least in line with the earth's estimated carrying capacity (Ayres, 1997). The ESCAP suggests the following eco-efficiency elements to be taken into consideration when assessing the eco efficiency profile of a company: reduction in the material requirements, reduction in the energy intensity of goods and services, elimination, reduction in the toxic dispersion, enhancement of the material recyclability, maximization of the sustainable use of renewable resources, etc (ESCAP, 2009). When applied at macro level ecoefficiency can be described as the efficiency with which natural capital can be utilized to enhance socio-economic progress and growth. Improving eco-efficiency means enhancing the efficiency of how material inputs are converted into outputs with less impact to ecosystems and the environment as a whole.

Re-addressing the above stated, the IEC is a concept that elaborates on industrial systems and on the process of their transformation towards evolution, continuity and sustainability. It elaborates on the substance flow within various units of production-consumption as well as between the system and the natural environment. Together with the technological change that is needed to bring this flow in balance and synchronization. When transposed into practice of particular usefulness are the principles developed by Tibbs, as described bellow, that serve as a guidance for governments, companies together with the consumers on the road towards sustainability (Koppen, 2004):

- Connect individual firms into industrial ecosystems
- Balance inputs and outputs to natural ecosystem capacities
- Redesign processes and products
- Align policy with a long-term perspective of industrial ecosystem evolution

The concept is relevant to the current research as it will help identify the most important environmental flows within the IT sector and assess their bottlenecks through entire metals life cycle. Further an analysis of these bottlenecks in relation to metals recycling and recovery will be performed. The principles elaborated by Tibbs, will help to additionally identify and evaluate the uptake of the concept by industries and the current opportunities and bottlenecks in connecting individual firms from the EEE as well as the WEEE sector.

Nevertheless, the IEC is missing the social, institutional and policy dimension that would explain the identity of actors involved in managing of flows and technologies and to define the driving forces that motivate their actions concerning these aspects (Jackson, 1998). The *triangle model* argued by C. S. A. van Koppen as presented in figure 2 will provide a structured and comprehensive approach in assessing the current state in respect to metals recovery and recycling from WEEE (Koppe, 2004).

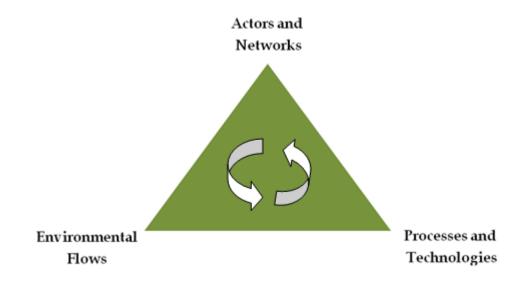


Figure 2: A triangle approach to Industrial Ecology Concept (after van Koppen, 2002)

2. 2 The Ecological Modernization Theory

The IEC provides and elaborates well on the desired sustainability relationship between the industries and the biosphere. It provides a set of prescriptions that industries should follow when designing processes and products to be in harmony with the regeneration limits of the biosphere. As mentioned above one of the IEC prescription refers to the desired state of policies by indicating that these should be "aligned with the long-term perspective of industrial ecosystem evolution". Nevertheless, the concept so far does not elaborate on theories and tools that should be applicable to achieve this sustainability transition. Therefore, it has been decided to apply the Ecological Modernization Theory (EMT) as a prescription theory that will provide for grounds to assess the current institutional aspects and the relationship between these and the components of the IEC triangle model, namely: flows - technologies and -actors. This will provide for the identification of those institutional aspects that need to be changed to be in line with the theory prescription and contribute to the environmental reform to take place in the electronics sector.

The conception of EMT goes back to a debate in the Berlin municipal parliament (22 January, 1982). Then, the environmental representative of one of the opposition political parties suggested national government four areas where the notion of ecological modernization needs to be introduced, namely: in several industries, in the energy, mobility and the construction sector (Jänicke et al., 1993). The reason for the theory to be introduced was also the fact that these industries needed employment. Stimulating innovations and ecologically relevant forms of rationalisation would not so much address the labour factor but the use of both energy and natural resources. Further, the EMT emerged in the context of the political modernization and innovation debate that was prevailing at that time. It was particularly stimulated by the scholars' search of a possible formula that would enable a redefinition and reorientation of established modernization ideas by confirming these with a strong ecological twist. Along this line, the theory was applied by the J. Huber and other researchers of the "Berlin school" of environmental policy, such as Simonis U., Prittwitz V., Mez L., and Weidner H., (Simonis, 1989) (Mol and Janicke, 2009). Initially, the EMT was primarily a political programme: promoted vastly by Janicke within the German environmental policy debate together with the academia support represented by the discourses of Huber. It was neither a theory, nor a concept which included the social dimension and it was mainly in between science and academia to be used as a practical and normative idea for initiating the environmental reform.

Few years later, the theory gained attention of scholars from the Netherlands and later from the UK and the Scandinavian countries who contributed to the theory development. Of particular influence was the work and interpretation of Spaargaren and Mol who refer to it as "a theory of social change" suitable for understanding the complexity of post-industrial society (Fisher and Freudenburg, 2001). Indeed, the theory emerged and developed as a response reaction to the neo-Marxist, de-industrialist and neo-liberal perspectives on industry- environment relationships which where of the belief that no significant environmental changes and/or reforms are possible under the prevalence of industrial capitalism. The EMT arose as a theory of completely opposite view and argued that only the industrial capitalism with its internal dynamics, mechanisms and institutions can bring the change and initiate the *reform* from unsustainable to sustainable practices.

In general, the EMT as a theory of change elaborates well on the societal and institutional components that need to be addressed if change (reform) is to be pursued. It explains the institutions role and

interconnectedness as well as the conceptual context in which the change may take place and along which sustainability concepts.

The EMT, as very radical to the believes at the time of emergence sees market actors as playing a leading role within the environmental reform to enter into new collaborative modes of work with state institutions in designing and implementing the sustainability transition. EMT stands and argues for environmental improvements as being economically feasible to implement. The theory treats technological innovations and continual industrial development as pre-eminent solution to deal with the current complex environmental problems and crisis. It acknowledges the political actors responsible for developing and promoting new and different policies and modes of governance in partnership with industries, non governmental organisations (NGOs), contribute and enable the actual environmental reform to take place.

Further, an elaboration on these lines in more details from the perspective of the EMT scholars will be presented.

Ecological Modernisation as a new form of economy development

In this sub-compartment, the role of the market, namely market actors such as private companies, industries, insurance and auditing companies and of the market based instruments is presented. Particularly the new relationship between the state such as state environmental authorities' officials and market actors in bringing the environmental reform is presented. This discourse on the market and on the need for new relationships between market and state primarily originated from the fact that at that time (1970-1980) the EMT emerged. The state was rather ineffective in solving the environmental crisis the society was confronted with. One example is Janicke's works on the state failure and the lack of preventive environmental policies in the European states to deal and manage the environmental problems in a preventive and sound manner. Notable is the message from Janicke's book on State Failure which begins with the following citation on the effectiveness of the governing regime from that time" It was clear to all that something should be done. All we agreed that we do nothing" (Janicke, 1990). His debate was complimented by Huber's work (Mol and Janicke, 2009), which elaborated well on the state failure and environmental bureaucracy as an obstacle for innovation. Huber explains in his works that indeed the legal foundation of environmental policy and regulation by environmental authorities is indispensable and is successful in some areas, such as add-on treatments of air born emissions, sewage and solid waste (primary and in large quantities). Particularly if the actors involved are not willing to accept their environmental responsibilities (Huber, 2009). Nevertheless, the scholars argue that any bureaucratic approach has a number of shortcomings such as: environmental laws are developed as prescriptions for a particular state of art and thus neither take into consideration the business cycles nor the differences between sectors and industries. Bureaucratic measures do not foster innovation and tend to be counter productive in certain ways. This particularly refers to the fact that bureaucratic measures are rather ineffective in stimulating companies to innovate, introduce new processes, new products, etc. As the scholar Hayek F., insists "bureaucracy lacks knowledge". This example is well illustrated by the case of chemicals industry when in 1990, the Federal Environmental Agency in Berlin, developed a list of 571 hazardous substances in response to which the chemical industry itself came with a list of more than 4 000 hazardous substances. This illustrates the knowledge available within the state and within the industry or in other words the places where problems are created are also the best places to find solutions because they have the necessary knowledge. This example also indicates the importance of industries in development and implementation of innovative ideas and the central role they may play within the environmental reform.

In this context, the EMT stands for two major innovative thoughts:

- First of all the societal image of the market with its main economic actors such as, producers of various goods, private insurance companies, retailers, etc. In this respect the EMT stands for promoting these actors as not the main cause of environmental degradation and pollution but rather as aligns and supporters of environment in other words industries with their knowledge, as in the case of the chemical industries referred above, can work best in favour of the environment;
- Second, the EMT introduces market actors as working in alliance with the state thus introducing new modes of governing and relationships between these. The EMT acknowledges the role of state in preservation of environment. Nevertheless, it stresses the need for new collaborative modes in instruments in reaching this aim that can be best implemented in consensus with market actors. The EMT argues that the state needs to transit from its bureaucratic, hierarchical, reactive and command and control modes of governing towards more flexible, creative and decentralized modes which are implemented in close cooperation with other societal actors, including market ones. The EMT calls for creation of various public private partnerships where environmental problems and solutions are addressed and developed in cooperation and consensus with other parties.

Ever since those early publications of Janicke and Huber and up till now scholars and adepts of the EMT have emphasised the need to rethink the role of the market and renew the relationship between the market and state if the environmental reform is to take place and maintain its due course.

Ecological Modernization as an innovative technocratic development

At the emergence of the EMT, the role of technology in bringing the environmental reform was very much debated, especially by the environmental advocates who where sceptic on the role technological innovation could play in bringing the change and considered as merely an intermediate to displace the environmental problem or move it from one medium and state to another one. This was particularly argued by scholars Murphy J., Gouldson A., and others, who emphasised and stressed on the technocratic mode of socio-environmental change (Murphy and Gouldson, 2000). It is considered that the works of J. Huber brought clarity on the indispensable importance of the technology in any successful program on environmental reform (Huber, 2000). The scholars believe that innovative technologies are the "key elements of an ecological modernization trajectory" (Mol and Janicke, 2009). Huber sees technologies and products which are particularly designed and developed to use clean and renewable energy, consume chemicals which have a low impact on the environment, selects materials according to their recycability and environmental, health and safety standards. Huber introduces a distinction between integrated technologies and end of pipe technologies, the latter is also called down stream technologies or add-on measures (Figure 3).



Figure 3: The Bi-directional model of environmental technologies Source: Huber, 2009

End of pipe technologies are defined as technologies to deal with the pollution after it has been caused, waste has been generated, or pollutants have been released. Among these are technologies applied in treating waste, waste water, capture of the air born emissions, etc. These technologies are followed by different types of materials recycling and reprocessing. For instance treatment of waste to recover materials that can enter into production systems as secondary materials, i.e. metals, plastic, glass recycling. The next step is technologies that aim to use materials more efficiently within the production cycles, thus various innovation may arise at various stages. Finally, there are technologies that take into consideration the hazardous profile of the substances to be managed by the system. These technologies go beyond the previous one and require development of entirely new technologies from the very beginning in combination with innovative solutions that enhance the overall performance of the system in which the technology is used. By this, the general goal of technological innovation can be distinguished. It is not any more merely on adding of measures. It is about finding innovative integrated solutions for the system itself where the technology is the motor of the innovation and can allow these gains to be obtained.

EMT distinguishes two major areas of technology interpretation (Mol and Janicke, 2009):

• The *evolutionary state of technologies* from being end of pipe technologies towards preventive and clean production technologies. The attention is focused on the very source of pollution and the hazardous content of substance that enter the production systems in order to be eliminated and thus pollution being prevented and products being cleaner and friendly to the environment;

• The *technology contextual application*, in other words the technological transition from individual technologies towards development and implementation of more complex sociotechnological systems. In this second notion the EMT implies that focus should not be on individual technologies and their implementation but on their functionality on the system level. Further the theory blends the role of the technology with the new management concepts, new ownership relations, new prising mechanisms, new roles of the state and the like.

The previous, clearly defines the transition route from end of pipe technologies towards more integrated innovative solutions with technologies being one of the constituent part. These will be planned and implemented within the frame of ecological management system which in turn is becoming more integrated at the company and industry level from research and development to design and production going even beyond that to marketing and after sale services (Huber, 2009).

Ecological Modernization as institutional learning for political programs

In this sub-compartment, the EMT in relation to environmental policies and decision making process is presented. The EMT, as explained by Hajer, calls upon understanding of the environmental problems and their consideration when developing and adopting new environmental policies and management programs. Hajer sees environmental crises as conceptual problems whereas environmental degradation is seen as "externalities" to those problems. "Integration" is the conceptual solution that is needed in order to deal with and to prevent the emergence of new environmental crises (Hajer, 2009). In scholars' opinion, environmental crises are the result of societal institutions wrong assumption that environment is a free good or a sink for human induced pollution and resources are available in endless amounts so pollution dissolves and has no effects on local, regional and global level. Nevertheless, the scholars believe that the same institutional actors "have the ability to learn" and that the process can produce meaningful changes in dealing and preventing new crises. Thus, the institutional learning perspective implies that environment is a new and essential subsystem and the integration of ecological rationality is a key variable in social decision making. Hajer gives a leading role to scientists which should create a language and communicate it in such a way that decision making takes environmental concerns into consideration. The scholars call upon the development of a specific set of social, economic and scientific concepts that make environmental issues calculable and facilitate social rational choice. Hajer consigns natural scientists with the task to develop "optimal exploration rates" and "rating and assigning ecological values" to resources so that to facilitate their application, engineers to design appropriate technologies in line with the above mentioned rates whereas social scientists to reflect on the needed changes in the societal environmental behavioural pattern.

Among the same line of thinking scholars as Spaargaren and Mol (Spaargaren and Mol, 2009) interpret and apply the EMT as an outline to guide the development of political programs. The EMT describes the paths to be taken to solve the environmental problems of modern societies which are driven by economical growth and goods consumption. Different scholars give different classification and interpretation of strategies to be taken to address the environmental problems. Summarizing on these, Spaargaren and Mol conclude on 2 main political programs in addressing and solving the environmental crisis present in Europe (Western Europe) from 1970 on wards.

 The first one focuses on compensation for environmental damage and on the use of additional technology to minimize the effects of growing production and consumption on the environment. This program can be characterized as a top-down state environmental policy with broad strategies, end of pipe technologies and final goals between the state environmental authorities, the industries and the non governmental organizations;

The second, which is considered to be in line with the EMT, focuses on altering processes of
production and consumption. This political program is a strong supporter of clean
technologies, economic valuation of environmental resources, changes in consumption and
production systems, prevention policies and management programs as well as monitoring
of compounds and quantities entering and leaving our production and consumption
systems, etc;

Concluding, the work of Mol and Spaargaren contributed essentially to theory development but also attraction of attention from other scholars which entered the domain and contributed to theory maturation (Mol and Spaargaren, 2000), (Mol and Spaargaren, 2005), (Mol, 1996), (Spaargaren, 2000), etc. The EMT established the foundation for new approaches in environmental governance, environmental policy content and formulation, policy instruments and actors' participation in decision making process (Janicke and Jorgens, 2009). "Governance" is an umbrella term for diverse state and non state political control exercised at different policy level against a complexity of actors and the operating environment (Hooghe and Marks, 2003). Environmental policy addressing current predominantly global environmental problems via policies which are set at different levels, sectors, addressing different interests and applying different instruments, have been particularly quick in adopting this concept of governance. This leads to several changes in environmental governance to emerge, such as development of policies which are target oriented, sector integrated as well as the emergence of new policy instruments based on labels and voluntary agreements, new forms of decision making based on cooperation and participation (van Koppen, 2002). Traditional forms of hierarchical interventions are increasingly being supplemented by new forms of cooperative governance.

Although, the EMT is still much debated on aspects such as economy against ecology, technocratic or democratic, etc., (Christoff, 1996) (Buttel, 2000). At current time, it can be firmly confirm that the EMT has produced a real change in the thinking about nature and society and in the conceptualisation of the environmental problems in the cycles of both the governmental and industrial actors.

Combined together, the IEC and the EMT will provide a comprehensive and integral conceptual framework by providing and elaborating on the main principles according to which metals from WEEE should be managed, processes should be designed and institutions interact in managing of these (figure 2).

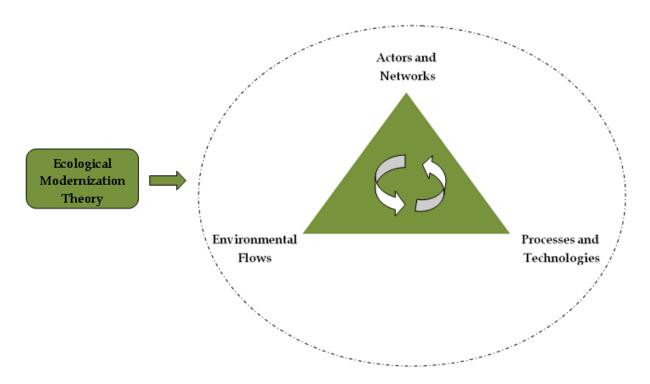


Figure 4: A triangle approach to evaluate metals recovery and recycling from WEEE in line with the Industrial Ecology Concept and Ecological Modernization Theory

2.3 Environmental theories and the reform in the WEEE sector

Following the elaborations on IEC and EMT in the previous section, in the current section, the provisions of these into the WEEE sectors are translated. This is done with the purpose to envision a system in line with the provisions of the environmental theories, help create the framework for future changes and the directions which need to be taken into consideration. According to IEC and EMT sustainable and self-sufficient systems, are all about balance and harmony between its components, innovation and integration of its technical means and application of creativity and flexibility in achieving these means. In WEEE sector, a balance is essential in managing environmental flows beginning with extraction and application down to their recovery and return into production. Harmony is about no boundaries between waste and resources as these are vanished and the residuals of one activity are inputs for another one. Sustainable and selfsufficiency systems are innovative and integrative. It is about technologies which are not treated independently as evolutionary units for their "hardware" functionality but as contextual sociotechnological applications combined with new management concepts and the like. Such systems are creative and flexible. These are the key words in policy development and decision making processes. In such systems the state is cooperative, applying a variety of approaches and instruments to guide and engage with society actors. The role of the state is to safeguard the ecological minima, to perform strategic design functions and define long term environmental objectives, whereas market actors are motivated to go beyond the minima by using specific innovation capabilities. Such systems open a myriad of avenues for innovation, prosperity and well being for its creators and beneficiaries for the current and future generations.

In this context, both the IEC and the EMT as environmental theories as well as political programs for sustainability reform are of particular relevance to provide for principles to guide the change and direct the system towards sustainability and better governance of its resources.

According to the current study we look at the WEEE system from the perspective of Environmental Flows – Technologies - Actors. Thus, the changes that need to occur in WEEE system are addressed from this perspective:

Environmental (Metals) Flows

The IEC provides an array of tools on flow assessment as well as principles according to which these should be managed so that various environmental, economical and social benefits are obtained:

The input of metals in our production systems is in qualitative/qualitative balance with the output of metals (extraction, application vis-à-vis recycling). Concerning the metals from WEEE this postulate implies that the quantity of metals that where applied in EEE manufacture should be recovered in similar quantities from the end of life EEE. Secondly, metals applied in EEE after being recovered should be up cycled to the same quality when these where initially applied in EEE manufacture.

Metals flows are managed in closed loops and in cyclical approach. This postulate resembles the characteristics of type III industrial systems proposed by Jelinski (Jelinski, 1992) where metals are used in closed but also cyclical loops and which is regarded as a form of ultimate sustainability. It implies that metals from WEEE after being recovered are used as input for another activity. For instance manufacture of new EEE. Further, this type of management of metals in closed loops is extended to go further so that metals are used repeatedly. The quantitative and qualitative aspects of the metals are preserved which diminishes the need to extract new virgin metals, release emissions to air, water and other environmental impacts associated with the extraction of metals.

Dematerialisation and Eco-efficiency are central to application in flows. These two concepts promote an intelligent and sustainable use of environmental flows. According to their definitions, the quantitative amount of environmental flows which are needed to support our systems will need to be drastically reduced. Secondly what will be used needs to be used in an innovative and efficient way. These two concepts have a strong link with the EEE domain implying that fewer resources will be needed to fulfil the modern societies needs and second the application of resources will be done in an efficient way in tandem with products which are free of toxic substances, scarce materials, are designed for reuse, recycling, etc.

Processing Technologies

None of the actions mentioned above would be possible without technologies being in place allowing these transformations. Technological innovation is at the heart of both the IEC and EMT. These require technologies and products to be designed and developed using clean and renewable energy, low impact chemicals, bionic design of products and selection of product materials according to recyclability and to environmental concern, health and safety standards. Technological innovation leads to prevention of metals being consumed, then efficiently applied to finally better recovery and recycling of these. Innovative and sustainable technologies are generally

designed to generate less impact on the environment, create better and safer working conditions for the workers.

Technological and product innovation will have an order. Consumption of metals and respectively waste generation will be primarily guided by the prevention principle, also mentioned by the waste management hierarchy. The changes will initiate in the electronics sector where prevention will mean that products will be manufactured addressing such terms as durability, flexibility and adaptation. There is no reservation to say that products will become, where possible, free of toxic substances and will be based on organic components. Products will have a longer life span and will redeliver better quality and provide customer added value. It will also be at the design phase when design for disassembly and compatibility for recycling processes will be taken into consideration. At the end of the life span, products will be primarily considered for remanufacture: refurbishment, cannibalization and reuse. Only after, the product may enter the recycling and metals recovery processes. Recycling and recovery technologies will need to transit towards systems where shredding techniques are substituted as much as possible by disassembly techniques and favour the extraction of components that may be reused and remanufactured. In such system there will be no waste as such as metals will be returned back via local micro loops as much as cross border macro loops back into production.

Technological improvements go along with Economical improvements. This postulate implies that a business strategy of ecological modernisation based on integrated and innovative solutions, ecological benign processes and product innovation are in line with the demands of the penetrating competitive green economy markets. It goes along the lines that being green and innovative leads to process productivity, adds to company competitive advantage on the market and it does pay off. An industrial entity from the WEEE sector in close cooperation with the actors from the EEE product chain pursuing such strategy, will extract more value from a defined amount of resources, will have less costs concerning environmental compliance and will create less impacts to the environment.

Integration and innovation are key concepts applied in any technology and product development. According to Huber (Huber, 2009) bi-directional model of environmental technologies, the path of transition from unsustainable towards sustainable practices lies in the transition from end of pipe technologies to integrated and innovative solutions. The WEEE envisions that products will be treated in sophisticated and innovative plants that allow cost effective recovery of, where possible, all materials which where initially applied in the EEE manufacture. It is no doubt that technologies will tend to be low in carbon and based on alternative energy sources. However, these technologies will not stand alone but being part of integrated solutions which will be planned and implemented in the frame of the company, industry, chain level, taking into account developments in research, products design, manufacture and going beyond that to finance, marketing and after sale services. The idea behind the "integration and innovation" is very strong. It explains that technologies alone will not be able to achieve the sustainability results modern societies are striving for. It is the combinative result of various technical and non-technical components of the system that can bring about the desired environmental change.

Diffusion on new EEE management concepts as technological integration measure. Many companies see Product Service System (PSS) as an excellent vehicle to enhance competitiveness and to foster sustainability simultaneously. Various benefits can be harvested along the (W)EEE product chain. PSS enables for better management of the product and materials flows both upwards and downwards in the supply chain. It is important to distinguish PSS as an internal

chain driver for optimisation of materials application, as a factor supporting of the DfE, manufacture of goods which are more durable, better recyclable, as all of these are in the PSS model an internal interest and not imposed as an external factor. PSS business model allows firms to create new sources of added value and competitiveness. They fulfil client needs in an integrated and customised way, can build unique relationships with these and enhance customer loyalty. These innovate faster as they follow their client and market needs. PSS integrate the views of economists, environmental engineers and customers as it defines a common language understandable to everyone.

Innovative technologies are clean technologies causing less environmental and human health impacts. The postulate debates on the fact that clean technologies generally generate less emission to air, water and soil thus cause less impact to these environmental components and to related flora and fauna that inhabit these. Clean technologies may also imply that the processes use additives, chemicals which are for instance less toxic or is water based, thus creating a safer working environment for workers directly involved in the manufacturing process, such as manufacture of EEE, later on a safer using environment for consumer as well as for the end recycler of WEEE.

Metals Governance

Comparing to the IEC, the EMT is particularly useful in describing the framework for sound governance of metals from WEEE. First of all, the EMT provides for new policies, policies instruments and new modes of governance in comparison to the traditional solely target oriented policies and command and control modes of governance. The EMT involves changes in the traditional role of state by supporting the creation of hybrid arrangements among different social actors, connection of stakeholders in the "WEEE chain" as well as introduction of new EEE management concepts that take the entire life cycle of the product into consideration. In respect to these the following changes are needed:

Coherent and objective policies from both environmental as well as economical point of view. First of all any policy should address and derive from an environmental problem. It should be developed in consensus with the industry actors, be knowledge based and take into consideration R&D framework and business investments cycles. Thus, if there are any policies to be developed in relation to economic important metals, the problems of their continuous depletion should be acknowledged as an environmental problem. The proposed policies should be well integrated in other industries sectors policies where metals are applied so that policies are coherent horizontally as well. The EMT is supportive of market based instruments which may enhance policy acceptance and implementation. Market based policy instruments encourage behaviour though market signals rather then through direct control and command style regulations. These allow for flexibility in achieving the policy goal, encourage technology innovation and are not bound to certain technology and performance based standards. Among these could be charge systems, reducing market frictions, government subside.

Environmental depletion of metals consumption is internalized. The postulate comes against the common believe that "Environment and resources are free public goods" in need for state action. The impact caused to the environment due to metals mining, application, limited recovery and recycling, the impacts on the landscape, local flora and fauna, local inhabitants should be internalized. Sound policies as well as market based policy instruments as described above may be of usage in this respect. In the case of WEEE it is important to bear in mind that the instruments will need to address both the behaviour of the user and the use of the natural resource itself. Well

thought design and implementation of these will be crucial in respect to the desired result and the effectiveness of the instrument.

New role of state actors vis-à-vis non state actors. The future envisions that the role between these two in managing and protecting the environment is changed with more opportunities for non-state actors to take over the traditional tasks of the state. In the new context, the state actors present at various policy levels serve as "guarantors" if activities transferred to non state actors fail to deliver the desired environmental and human level of protection. The role of the state actors can be empathised here in the identification of the environmental problem to serve as a powerful signal to the targeted sector. In respect to economical important metals continuous depletion, state authorities will have to play a particular role in wide acknowledgement of the problem, development of a required regulatory framework with introduction of a range of performance standards. Private sector in response either innovates or is subject to state sanction-based regulatory laws.

Supporting of "hybrid partnerships" between various actors within and along the WEEE chain. The state should facilitate industries participation in decision making but also in creation of various Public Private Partnerships to address complex environmental problems which are persistent in long term and foster sector/product/materials use innovation. With respect to WEEE sector this means that close cooperation should not only be between recyclers and metals refineries but go beyond that to include the EEE manufacturer. Commitment along the product chain is very important to ensure that one actor's efforts are supported and continued by the following actor in the chain. Further, by connecting stakeholders along the WEEE and EEE product chain may bring various environmental and financial benefits that individual parts of the chain are likely to fail to obtain.

Identification of pioneers to facilitate reform development and serve as a model for others. Finally it is very important to identify and engage large companies which can facilitate the process of transformation. In the WEEE sector, this may be large metals refineries companies, although the majority of power to perform a desired change lies with the EEE manufacturers. It is well known that larger manufacturing companies have better resources and possibilities to engage in R&D, developing new products that are better designed for the chain management, including end of life management. EEE manufacturing companies are better to create new innovative products in form of niches in the market that can ultimately revolutionize both the market and the governing regime. Large companies can be good support for the upstream smaller companies by engaging the latter in various energy and materials efficiency projects, train and educate these on sustainability matters. In good cooperation with downstream companies these can increase the value that can be extracted from the end of life equipment. Overall, EEE manufacturing companies are better in engaging consumers in communication and development of awareness. Large companies can serve as a model, a pioneer to be followed, facilitate and guide the process towards sustainability.

III OVERVIEW OF THE WEEE SYSTEM WITH FOCUS ON THE NETHERLANDS

The chapter introduces the WEEE system with the focus on the Netherlands. It begins with the introduction of the main metals which are central to this study. Further, the actual WEEE system is described in line with the flows-actors-and-technologies triangle model. The chapter concludes with the description of the EU and national legal framework according to which the system operates.

3. 1 WEEE Material Composition

The present is an overview of materials which are applied in the manufacture of electrical and electronic equipment (EEE) with particular emphasis on metals. In order to have a better understanding of metals flows and the issues surrounding the metals throughout their life cycle, 3 metals have been selected: Indium (*In*), Gallium (*Ga*) and Ruthenium (*Ru*) to be described in greater details. These three metals have been selected due to their share of application in IT electronics sector. The metals are described against such criteria as: global reserves and distribution, metal application, current and future demand, price as well as availability of substitutions and recycling technologies.

From material composition point of view EEE are complex products which may comprehend more than 40 elements of the periodic table (Hageluken, 2007). A mobile phone is a good example of a complex devise from material composition point of view. Nokia reports that a mobile phone may consist of up to 500-1000 components depending on complexity (Nokia Report, 2005). In the phone, the mechanical components like housing are usually manufactured of polymers, a large class of natural and synthetic materials, whereas the electrical and electronic components mainly of metals. The figure 5 presents the composition of a typical mobile phone (Lindholm, 2003).

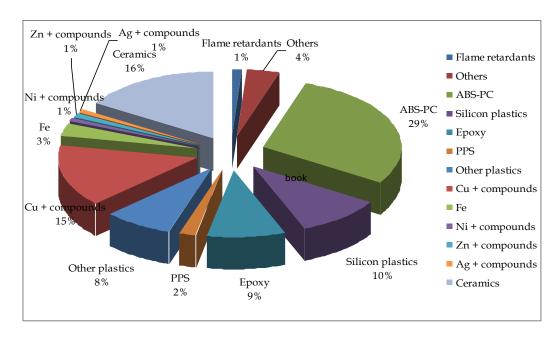


Figure 5: Typical material composition of a mobile phone

Metals represent on average 23% of the weight of a phone, the majority of this is copper. Additionally to the copper the diversity of metals is complimented by such metals as silver (Ag), gold (Au), platinum group metals (PGMs) which together form the category of precious metals, aluminum (Al), nickel (Ni), zinc (Zn), iron (Fe), indium (In), antimony (Sb), bismuth (Bi) and other which form the base and special metals, beryllium (Be), cadmium (Cd), arsenic (As) and other toxic elements which due to their hazardous nature form the group of metals of concern. Additionally to metals there are such materials as halogens, plastic, organics, glass and ceramic materials.

Indium (In)

Indium is a silvery white, brightly shining heavy metal with the chemical symbol *In* and atomic number 49. Indium was first discovered by chemists Ferdinand Reich and Hieronymous Theodor Richter in 1863 in Germany who named the mineral for "indigo" spectral lines created on the spectrograph. Indium forms alloys with most other metals by confirming to the latter strength, corrosion resistance and hardness. Indium tin oxide (*ITO*) is both transparent and conducting which make it essential for display application.

Indium abundance in the continental crust is estimated to be approximately 0.05 ppm (USGS, 2011). The geochemical properties of indium are such that it only occurs with other base metals such as copper, lead, and tin and to a lesser extent with bismuth, cadmium, and silver, which are considered sub-economic for indium extraction. The recovery of indium from zinc ores is most common (Felix, 2000). Around 0,028 kg of by product of indium can be recovered from 1 t of zinc ore (Jorgenson, 2005). Thus, Indium is an example of one of the metals which are "by products" of a main carrying metal extraction, i.e. zinc. The world indium reserves base were estimated to be 16 000 metric t in 2008 (USGS, 2008)³. The world mining production of Indium in 2010 added up to 574 metric t of primary indium (USGS, 2011). Overall indium production can be regarded as continuously increasing (Figure 6). On the world scale Chinese mines convey 50% of world's primary indium, followed by Republic of Korea, Canada and Japan, which has no natural indium reserves but a well developed recycling system (Tolcin, 2008). There is an estimation of approximate 600 t of secondary indium originating from recycling activities (Oko Institute, 2009).

³ According to USGS [2011] reserves are dynamic data and estimates. They may be reduced as ore is mined and/or the extraction feasibility diminishes, or more commonly, they may continue to increase as additional deposits (known or recently discovered) are developed, or currently exploited deposits are more thoroughly explored and/or new technology or economic variables improve their economic feasibility. Thus "Reserves may be considered a working inventory of mining companies' supply of an economically extractable mineral commodity". As such, magnitude of that inventory is necessarily limited by many considerations, including cost of drilling, taxes, price of the mineral commodity being mined, and the demand for it.

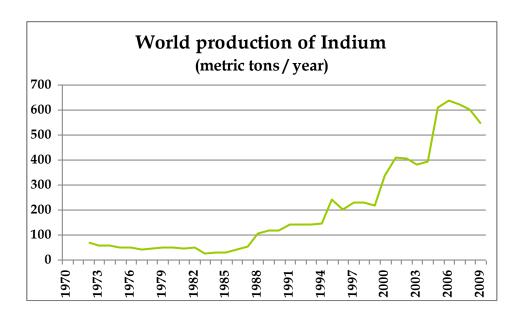


Figure 6: Indium World Production 1970 - 2010, Source U.S. Geological Survey

Most of the indium applications include (Figure 7):

- 1) Thin films made out of ITO are mainly used for liquid crystal displays (LCD) applied in monitors, televisions, notebooks, cell phone displays, electroluminescent lamps;
- 2) Manufacture of alloys, solders and semiconductors, i.e. indium semiconductor compounds are used in infrared detectors, high-speed transistors;
- 3) Manufacture of solar cells (PVC).

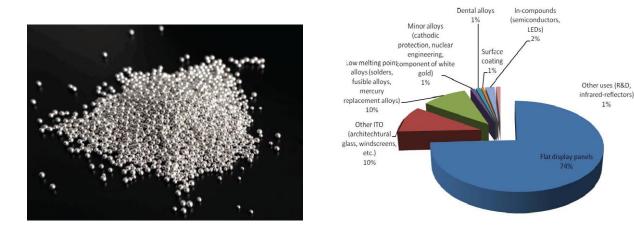


Figure 7: Indium pearls (on the left), Indium application (on the right) Source: Umicore Group, Indium application: EC, 2010.

Due to vast areas of application, price volatility as well supply concerns contributed to a range of research and assessment reports which elaborate on metal demand and supply issues. Few

predictions have been made in this respect (Oko Institute, 2009, EC, 2010). The Oko Institute made estimation on future demand of indium which is 5% to 10% as annual growth of indium demand in the next 10 years (Oko Institute Report, 2010). This is mainly due to the growth of sectors where indium is currently applied as well future application of ITO in Organic Light Emitting Diodes. These are regarded as highly innovative and will mark the next generation of flat panel displays. Indium is also applied in copper-indium-selenide thin-film solar cells which are potential new type of solar cell for more easy, sustainable and cheap production (Fraunhofer Institut, 2009).

Due to ITO demand attributed to the technical changeover towards LCD applications, indium prices rose starting from 100 USD/kg in 2003 to 900 USD/kg in 2006. Currently indium price is approximately 500 USD/kg in 2010(USGS, 2011).

Recovery of Indium from ITO has become an economically and environmentally justified method (Virolainen et al., 2011). Sputtering, the process in which ITO is deposited as a thin-film coating onto a substrate is highly inefficient. Approximately 30% of an ITO target material is deposited onto the substrate whereas the remaining 70% consists of the spent ITO target material, the grinding sludge, and the after-processing residue left on the walls of the sputtering chamber. ITO recycling is concentrated in China, Japan, and the Republic of Korea, countries where ITO production and sputtering take place. Further, technologies have been developed to recover indium from LCD scrap panels, which crush the panels in millimeter-sized particle, soak them in acid solution to dissolve the ITO from which indium is recovered. Although indium concentration in these tailings is low, the activity has become economical viable due to increased price of the metal. Nevertheless, recycling facilities for In-containing old scrap are only partly installed and initiated, i.e. in Belgium by Umicore (Hagelüken, 2010). Recycling is mainly problematic due to dissipative and widespread applications of indium in EEE applications and solar cells. Due to this, a number of smelters around the world have accumulated large amounts of tailings and slags to be treated when economical feasible.

Concerning possible substitutes, researchers from the field of electronics material makers consider zinc oxide as an alternative for indium which may reduce the use of indium in various applications (USGS, 2011). Indium has substitutes in many, perhaps most, of its uses. Nevertheless, the substitutes usually lead to losses in production efficiency or product characteristics. Silicon has largely replaced germanium and indium in transistors. Although more expensive, gallium can be used in some applications as a substitute for indium in several alloys. Another possible substitute for indium glass coating is transparent carbon nanotubes, which are untested in mass production of LCDs. Indium phosphide can be substituted by gallium arsenide in solar cells and in many semiconductor applications.

Gallium (Ga)

Gallium is a silvery white metal with the chemical symbol *Ga* and atomic number 31. The metal is brittle and solid at low temperatures and it liquefies slightly above the room temperature. The metal was discovered in 1875 by the chemist Paul Emile Lecoq de Boisbaudran, who identified it spectroscopically for its two violet lines spectrum during the examination of a sphalerite sample. The chemist named the mineral after the Latin name *Gallia*, meaning gaul (a region of Western Europe during the Iron Age and Roman era), after his native land of France. Gallium is mainly used as a compound with arsenic as gallium-arsenide (GaAs), which is important as a semi conducting material.

Gallium occurs in very small concentrations in ores of other metals. Gallium abundance in the earth crust is estimated to be at 16,9 ppm. Most gallium is produced as a "by-product" of bauxite processing and from zinc processing residues. The global production of primary gallium was estimated at about 106 metric tones in 2010 (USGS, 2011). Overall gallium production can be regarded as continuously increasing (Figure 8). China, Germany, Kazakhstan and Ukraine were the leading producing countries with lesser output then Hungary, Japan and Russia. Due to the fact that only part of the gallium present in bauxite and zinc ores is recoverable, the USGS states that an estimate on reserve according to the definition of reserves of other minerals can not be made (USGS, 2011). Nevertheless, the world bauxite reserves are so large that much of them will not be mined for many decades, thus geological scarcity is not an issue for the metals. The Oko Institute gives an estimation that the largest reserves of several million tons of gallium are in phosphate ores and coal with a low gallium content of 0,01%-0,1%.

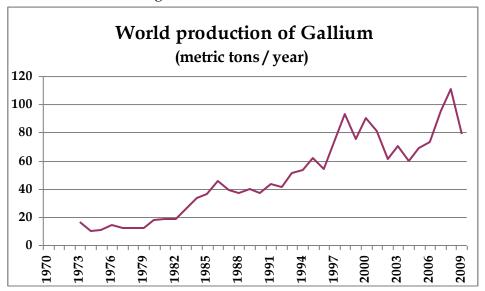


Figure 8: Gallium World Production 1970 – 2010 Source: USGS, 2010

Most of the gallium applications include:

- 1) GaAs is important for the production of integrated circuits applied in high performance computers and telecommunication equipment;
- Gallium is applied in manufacture of laser diodes, photo detectors. These microelectronic devices are then used for manufacture of optoelectronic components which are applied in aerospace, consumer goods, industrial and medical equipment and telecommunication;
- 3) Special alloys for high temperature applications;
- 4) Manufacture of solar panels based on gallium.



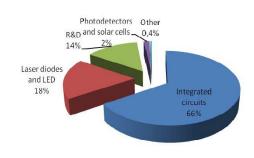


Figure 9: Gallium photo (on the left), Gallium application (on the right). Source: Gallium application: EC, 2010

The price for gallium slightly started to increase after 1990 with fluctuations and a peak in 2007 from about 325 USD/kg in 1994 to 400-600 USD/kg in 2008. In 2010, the prices also fluctuated between 340 USD/kg at the beginning of the year to 650 USD/kg at the end of the year (USGS, 2011).

As indium, gallium has large current and future arias of application. The Oko Institute made estimation on future demand of gallium which is up to 10% as annual demand growth during the next 10 years (Oko Institute, 2010). This growth in demand is also due to the fact that for around 40% of the gallium applications substitution by other materials is difficult or impossible (NRC, 2008).

Substantial quantities of new scrap generated in the manufacture GaAs base devices are reprocessed. Gallium is not recovered from old scrap such as WEEE.

Liquid crystals made from organic compounds are used in visual displays as substitutes for LEDs. Researchers are also working to develop organic-based LEDs that may compete with GaAs in the future. Silicon is the principal competitor with GaAs in solar cell applications (EC, 2010).

Ruthenium (Ru)

Ruthenium is a silvery white metal represented by the symbol Ru and atomic number 44. It is a rare transition metal belonging to the platinum group metals (PGMs), which embodies another 5 metals: Rhodium (Rh), Palladium (Pd), Osmium (Os), Iridium (Ir) and Platinum (Pt). The metal was discovered by the Russian scientist Karl Ernst Claus in 1844 and named it after the Latin name Ruthenia, which refers to part of the Russian, Ukraine and Belarus region and people. Most ruthenium is used for wear-resistant electrical contacts and the production of thick-film resistors and in platinum alloys. PGMs are well known for strong catalytic activities.

PGMs are very rare metals in the earth's crust with ruthenium abundance estimated to be of approximately 1 ppb (BGS, 2009). PGMs occur and are mined always together as "coupled elements" with platinum and palladium as major metals, while average rhodium and ruthenium output is about factor 10 and iridium and osmium about factor 50 lower than platinum and

palladium. Deposits are further associated with nickel, copper and gold and in these the concentration of rhodium, ruthenium, iridium is poorer. Close to 90% of the world's PGMs reserves are located in South Africa, which is also the global leader in platinum production (USGS, 2010). The world reserves of total PGMs in 2011 were estimated to be 66 000 tones (USGS, 2011). There is no aggregated and recent data officially published on Ruthenium individual reserves and production. The PGMs production as in the case of the first two metals display a general continuous increasing trend (Figure 10).

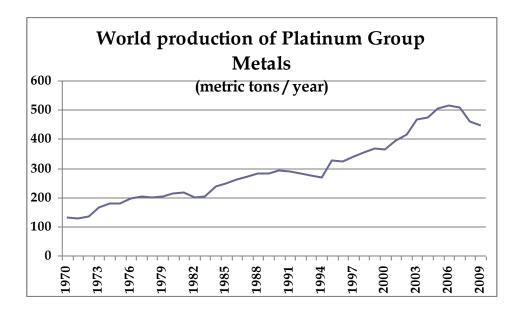


Figure 10: PGMs World Production 1970 - 2010

Pure ruthenium is rarely used by itself because it is extremely difficult to work and it remains hard and brittle even at temperatures as high as 1500°C. Nevertheless,

- 1) Ruthenium is a useful addition to Pt and Pd to impart hardness and to improve resistance to abrasion in electrical contact surfaces;
- 2) In electronics industry ruthenium is largely applied in manufacture of computer hard discs to increase the density at which data is stored;
- 3) In chemicals industries, ruthenium has some important applications on account of its good catalytic activity and resistance to corrosion and stability under varying operating conditions.

At the PGM level, the metals are applied in auto, chemical industry and petroleum refining as catalysts. Minor applications include glass making equipment, especially LCDs. Due to their high prices, PGMs, including ruthenium are used as investment tools.



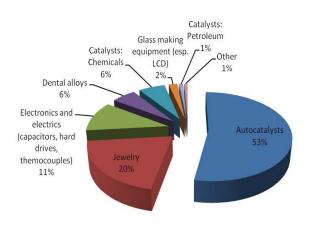


Figure 11: Ruthenium photo (on the right), Ruthenium application (on the left) Source: Ruthenium application: EC, 2010

Ruthenium price has shown an almost continuous increase in the last 20 years. The price of ruthenium reached the pick between 2006 and 2007 with 31064 USD/kg. This is explained by the increased global demand of PGMs in various applications. The price then dropped dramatically in 2009 to stabilize in 2011 at 6354 USD/kg⁴.

There is no individual forecast concerning ruthenium future demand. Nevertheless, PGMs are expected to play an important role in emerging clean technologies and in the developing markets of China and India. Several interesting future applications are: "Four way catalysts" in car engines to control the gas and particulate emissions in one single system, use of ruthenium and rhenium in nickel-based super alloys that are used in turbine blades for jet engines and in fuel cells.

Due to their high value, recycling of PGMs is quite efficient, especially from industrial process catalysts (Hagelüken, 1996) (Hagelüken and Verhelst, 2004) and glass industry. Recycling of PGMs from consumer applications however is much worse. For PGMs in electronic applications, recovery rates are probably only in the range of 10% (EC, 2010). The reason lies with a range of factors among which are the recovery rate of WEEE and dissipative application of ruthenium in EEE. Facilities to recover ruthenium from old scrap are in place in Belgium, Umicore Plant, Germany - Norddeutsche Raffinerie AG (Oko Institute, 2009) and Sweden Boliden Mineral AB.

3.2 WEEE Technologies

After being consumed, EEE enter the end of life phase and from this stage the equipment is regarded as WEEE. The overall task of end of life phase is to recover the raw materials as effectively as possible and to remove components with high hazardous potential. Several steps can be distinguished here: collection of WEEE, pre-processing and disposal (Chancerel et al., 2009). The purpose of collection is to ensure that equipment is recovered for treatment, recovery of materials as well as that the hazard content will not pose danger to environment and humans. After collection, WEEE is pre processed to produce materials. Depending on stream content and value, these are either used as secondary raw materials by various industries or are transferred to an end

⁴ http://www.ebullionguide.com/price-chart-ruthenium-last-5-years.aspx, Johnson Matthey base prices.

processing stage. An example are printed circuit boards which are sent to metals smelters and refineries for recovery of precious and other base and special metals (Chancerel et al., 2011). Preprocessing does also provide for the concentration of the hazardous substances, their environmental friendly removal and disposal, for instance in the case of batteries or other components containing cadmium and mercury. (Cui and Forssberg, 2003).

WEEE Pre -Processing Technologies

Pre-processing can be carried out manually, automatically (shredding and sorting of materials) or with a semiautomatic processes combining manual and automatic techniques. Pre-processing is usually divided into the two following stages: sorting and selective disassembly. This is done with the scope to remove hazardous or valuable materials and upgrade them using mechanical or metallurgical processing to extract the valuable materials (metals) (Chancerel et al., 2009). Preprocessing provides for different equipment to be separated into various fractions such as metals: iron, copper, aluminum, plastic, ceramics, and paper, wood. As well these provide for dives such as capacitors, batteries, various tubes and printed circuit boards to be separately removed. The range of materials is visualized in the Figure 12 (Cui and Forssberg, 2003). Each of these factions posses a different material composition and characteristic and thus will undergo different subsequent treatment. For instance plastic may undergo a different treatment due to their content of halogens whereas metallic fractions will need to enter a metallurgical treatment for their metals content. After passing the hand sorting the aim of which is removal of contaminated fractions the materials undergo a first size reduction and further separation (Spengler et al., 2003). A serious of magnets may be applied to remove ferrous materials. Reprocessing, multiple passes through the shredder and application of magnets is recommended in order to increase the volume of recovered ferrous materials (Stuart and Lu, 2000). Screens and grinders are applicable to separate materials in accordance with the size and collect fractions which need to be returned for shredding. Non ferrous metals are removed with application of eddy currents, electrostatics, air float sinking or centrifugal force (Hischier et al., 2005). Size reduction may also include subsequent shredding, grinding or hammer milling process connected by conveyors (Williams, 2007). In conclusion, the range of applicable technologies and technology configuration depends on composition of the scrap and further use of recovered materials.

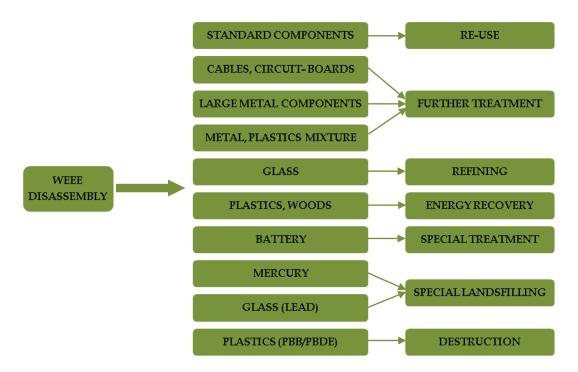


Figure 12: Typical recycling process of WEEE Source: Cui and Forssberg, 2003

WEEE Metals Recovery Technologies

Certain fractions as printed circuit boards and metal composites are rich in metals and particularly in precious and special metals. In order to be recovered these need to be treated using other methods such as pyrometallurgy or hydrometallurgy (Antrekowitsch et al., 2006).

Pyrometallurgy process is a complex process composed of the following steppes, such as smelting of feed materials into a plasma arc furnace or blast furnace, drossing, sintering, melting and reactions at high temperatures (Sum, 1991). The majority of electronic scrap and secondary copper is processed pyrometallurgically in a copper smelter. These use copper as the collector metal. The smelter includes such steps as reduction and smelting of the material, blister or raw copper production in the converter, fire fining, electrolytic refining and processing of the anode mud. The WEEE scrap is fed into the process in different steps depending on their purity and physical state. These will also influence the composition and quality of dust and slags. Among the variety of metals which can be recovered from WEEE is copper, nickel, lead, tin, zinc, iron, arsenic, antimony and a variety of other precious and special metals. Beside copper based process, lead smelting process as the main collector metal can be applicable for treatment of WEEE.

Hydrometallurgical processes consist of acid or causting leaching of solid materials. The metals containing in WEEE are recovered by applying the process of solvent extraction, precipitation, cementation, ion exchange, filtration and distillation (Gramatyka, 2007). Among the solvent which are applied by the industries are H2SO4 and H2O2, HNO3, NaOH, HCl (Antrekowitsch et al., 2006). Electrochemical treatment is refined processes and is conducted in aqueous electrolytes and sometimes in molten salts (Gramatyka, 2006).

Bellow is a schematic representation of recycling of WEEE containing copper (Figure 13).

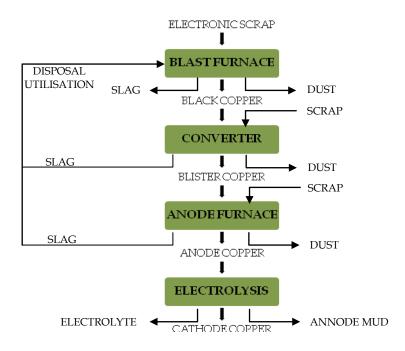


Figure 13: Recycling of WEEE containing copper Source: Gramatyka, 2007

3.3 WEEE Stakeholders

The diversity of actors which are connected to the WEEE system can be grouped in the following categories: EEE manufacturers, EEE consumers, WEEE collectors and WEEE recycling companies, both the dissemblers and the metals refineries. These actors are represented in figure 14, and are arranged according to the life cycle of the EEE.

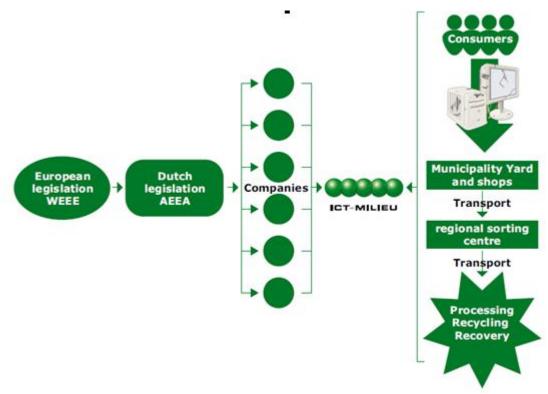


Figure 14: WEEE system stakeholders Source: ICT MILIEU Monitor 2011

The Compliance Scheme

According to the Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE) EEE manufacturers are administratively and financially responsible for the management of the EEE when these turn into the end of life phase. In the Netherlands, producers of EEE ensure compliance collectively via a foundation called ICT MILIEU. The foundation looks after the environmental interests of companies located in the IT, Telecom, Internet and Office sector. It relieves these companies from a maximum amount of work involved in meeting the producer requirements as drawn up in European legislation. Parallel to this foundation, there is another foundation called Wecycle (NVMP: The Dutch Foundation for the Disposal of Metal and Electrical Products) which runs a take back system for all the other WEEE categories such as large and small household appliances, electrical and electronic tools, toys, and monitoring and control instruments.

ICT MILIEU Foundation has been established in 1999 as division of the ICT Office Trade Association and is responsible for the day-to-day management of the ICT collection and recycling system. The foundation responsibilities are:

- Manage the ICT collection system;
- Maintain contacts with governments, politicians, other trade associations, social organizations and media at both the national and international levels;
- Perform management of reports, collection of information;
- Perform audits;
- Perform acquisition to ban free riders from the system;
- Provide participants with advice and assistance via the ICT Milieu helpdesk;
- Promote mutual contacts and an exchange of knowledge;
- Serve as the spokesperson for the ICT sector with respect to environmental issues.

In 2010, there were 272 manufactures affiliated to the ICT collection system. It is important to mention that besides ICT MILIEU there are several dozens of individual compliance schemes operating in the Netherlands, which did not fall under this research⁵.

WEEE management is financed by EEE manufactures. The ICT Milieu Foundation passes on the environmental costs to producers that in turn calculate this into the cost price of their products. The recycling fee is not visible on ICT equipment. The fee that producers pay to the CS is calculated based on the producers volume of products placed on the market, a system called the "market share". All companies have to make a declaration on the total weight of equipment put on the market in a certain period of time by categories of equipment as defined in the Dutch legislation. For reason of commercial confidentiality, the market share is provided to a "black box" operated by an independent third party. The party registers the incoming data concerning recycled amounts and invoices accordingly the participants. The cost related to management of historical waste from households is ensured by producers through current market share, and from business if the EEE was placed on the market after 2005. Producers are also responsible for EEE which was placed on the market before 2005 if a replacement was purchased. Otherwise the end user is to be responsible.

WEEE Collectors

There are several stakeholders which are involved in collection of WEEE. For instance in the Netherlands, municipal waste yards are involved in collection of WEEE. Every Dutch citizen and in some municipalities also certain small electronic shops are allowed to enter municipal waste yards to discard their WEEE free of charge. An additional levy will apply if a certain threshold of discarded WEEE is surpassed. Retailer shops are also involved in collection of WEEE. The old equipment can be handed in when a new similar product is bought from the shop. This system is known as "Old for New". Further, the retailer shops may discard the WEEE free of charge as well at the municipal waste yards, regional sorting stations, distribution centre of the shop or through the logistic services of the compliance schemes which arrange collection and recycling operations on behalf of the producers.

WEEE Recyclers

Beginning with 2011, the Netherlands compliance schemes, ICT MILIEU and Wecycle are working with two large recycling companies, namely Sims Recycling (part of the Sims Recycling Group) and CoolRec (part of the van Gansewinkel Group) which perform certain pre processing operations. Both companies have been selected after a tender procedure based on criteria such as approach to WEEE, technological performance, commitment to sustainability, safety and in house innovations on recycling processes. Sims Recycling is a global leader in metal and electronics recycling industry present in all 5 continents. The company is specialized in recovery of ICT equipment, such as computers, televisions, phones, etc. It offers refurbishment for distribution and remarketing and recycling for recovery of components and materials such as metal, glass and plastics.

⁵ For an overview on other compliance schemes, please see the following website of Agentschap NL: (http://www.uitvoeringafvalbeheer-tools.nl/produktbesluiten/list.asp?iid=1&categorie=1).

WEEE Metals Refineries

Most of the WEEE containing high content of precious but also base metals are refined in EU at one of the 3 companies which produce and refine metals for electronics industry. These are Umicore Group, located in Belgium, Aurubis located in Germany and Boliden Mineral AB in Sweden. In my study I will refer to Umicore Group as this is the metal refinery facility the Netherlands CS is working with.

The Umicore Group is a global materials technology group, which employs 14400 specialists and with an annual turnover of \in 9,691.1 mill EUR. Its activities are centred on four business areas: Catalysis, Energy Materials, Performance Materials and Recycling. Each business area is divided into market focused business units which offer materials and solutions that are important for clean technologies, such as emission control catalysts, materials for rechargeable batteries and photovoltaic, fuel cells but also those which are essential for our daily life. Recycling business area treats complex waste streams containing precious and other non-ferrous metals. The operations can recover some 17 precious and other non-ferrous metals from a wide range of input materials ranging from industrial residues to end-of-life materials. It covers precious metals refining from industrial intermediate materials, from precious metals-bearing scrap, from electronic and catalytic applications, from end-of-life rechargeable batteries and recycling of jewellery. The recovered metals are converted into semi-finished precious metals-based products (Umicore Report to Shareholders, 2010).

3. 4 WEEE Legislative and Institutional Framework

Polices at the EU level

The Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE) along with the Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment are priority areas that take specific measures to reduce impacts from WEEE on EU scale.

The Directive 2002/96/EC on Waste Electrical and Electronic Equipment

The WEEE Directive has been developed in the early 1990s as part of a shift in environmental legislation from processes to products. The driving force of the WEEE Directive development was the shortage of landfill capacity in the EU. The Fifth Environmental Action Program stated that "Management of waste generated within the Community will be a key task of the 1990s. Current upward trends in waste generation must be halted and reversed in terms of both volumes and environmental hazard and damage" (Castell, 2004). Although WEEE represented less than 1% of landfilled waste, the WEEE retained much attention and still does currently, due to the hazardous content that need to be taken care when products reached the end of life stage.

Thus, the Directive 2002/96/EC on WEEE was designed to set general organizational framework on WEEE. It defines the EEE products which fall under the scope if this directive, specific guidance and requirements for operators and actors which form the WEEE system and are bound to certain operational relationships in the course of the system management. The directive has been adopted under the provisions of the article 175 of the EC Treaty which means that the directive sets the minimum requirements for WEEE management and that Member States may formulate additional

requirements. The directive entered into force on 27 January, 2003. In line with the Article 1 of the WEEE directive, the main objective of the directive is:

.. prevention of WEEE, and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste. It also seeks to improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, e.g. producers, distributors and consumers and in particular those operators directly involved in the treatment of waste electrical and electronic equipment.

The Directive provides guideline on a range of management issues beginning with the collection and treatment of WEEE to financing, reporting and information for users, monitoring and penalties. It defines WEEE as originating from private household and other that private household. It distinguishes between WEEE collected before 13 August 2005 (historical waste) and EEE placed on the market after that day onwards. The directive requires Member States to adopt appropriate measures in order to minimize the disposal of WEEE as unsorted municipal waste. It requires setting up of systems that would allow final holders and distributors to return WEEE. It calls upon the involvement of distributors to allow for WEEE to be returned via the distributor on a one-toone basis. It provides for creation of individual and collective take back schemes that would be operated by producers. In order to be measurable the directive establishes collection and recycling targets. The WEEE Directive requires Member States to ensure a separate collection of at least 4kg/inh on average per inhabitant per year of WEEE from private household. It sets recovery and recycling targets which differ per product category. In the case of IT, telecommunication and consumer equipment, the directive sets a rate of recovery of 75% by average weight per appliance and a component, material and substance reuse and recycling of 65% by an average weight per appliance. The directive provides via the Article 6 and Annex II, general operational requirements and the need for appropriate facilities to treat the WEEE by setting norms on selective treatment for certain materials and components of WEEE. Additionally, the directive refers to the Council Regulation (EEC) No 259/93 of 1 February 1993 on the supervision and control of shipments of waste within, into and out of the European Community in order to ensure that WEEE treated outside the Member State Community has taken place under conditions that are equivalent to the requirements of the WEEE directive.

Central attention in the WEEE directive is given to the producer of EEE who in accordance with the provisions of this directive is administratively and financially responsible for the management of the EEE when these turn into the waste phase. The directive explains producers' responsibilities taking into consideration the distinction between WEEE from private household and other than private household as well as the date of EEE origin. It sets the information background and flow between the producers and consumers on issues related to product environmental aspects via product appropriate labelling and marking. Second, producers and EU/national authorities concerning the registration and format of reporting on EEE put on the market as well as between producers and treatment facilities on reuse and treatment information for each type of new EEE put on the market.

Further, the directive explains the importance of the consumer involvement in the WEEE system. It requires Member States to adopt measures so that consumers participate in collection of WEEE and encourage them to facilitate the process of reuse, treatment and recovery. This can be facilitated by providing consumer information on correct WEEE disposal, availability of the collection points as well as the potential affects on the environment and human health from improper disposal.

The role of EU and national authorities in respect to ensuring general guidance, exchange of information, reporting on directive implementation, monitoring and inspection of actors involved in the WEEE system and penalties is explained in the concluding part of the directive.

Directive 2002/95/EC on the Restriction of the use of certain hazardous substances in electrical and electronic equipment

The main objective of the Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment is to "approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment" (text retrieved from the 2002/95/EC Directive).

The 2002/95/EC Directive stipulate that, from 1 July 2006, 6 substances, namely: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers applicable to EEE must be replaced by other substances. Since, there are situations when it is not possible to completely substitute these substances, the 2002/95/EC Directive provides for a tolerance level of 0.1% for lead, mercury, hexavalent chromium, polybrominated biphenyl and polybrominated diphenyl ethers and a tolerance level of 0.01% for cadmium. The directive covers the same group of products which are listed under 2002/96/EC Directive on WEEE (except for medical devices and monitoring and control instruments). The 2002/95/EC Directive also applies to electric light bulbs and luminaires in households.

Currently, the 2002/95/EC Directive is under revision and one of the areas of revision is to develop and implement a mechanism allowing new bans to be introduced in line with the REACH Regulation (Regulation (EC) No 1907/2006). REAH is an integrated system for the registration, evaluation, authorisation and restriction of chemicals. It requires firms which manufacture and import chemicals to evaluate the risks resulting from the use of those chemicals and to take the necessary steps to manage any identified risk. Thus, it is very important to ensure a harmonization between the list of substances listed under the 2002/95/EC Directive and the conclusions of the REACH. This is particularly the case when new substances are evaluated as highly toxic to human health and environment and are not listed under the 2002/95/EC Directive.

Policies and institutions at the national (The Netherlands) level

The Netherlands has transposed the provisions of the above mentioned directives into national legislation through the following legislative documents:

- The Environmental Management Act (Law of June 13, 1979)
- The WEEE Management Regulations (Regulation of July 19, 2004)
- The WEEE Management Decree (Decree of July 6, 2004).

The Environmental Management Act is an umbrella act setting general governing rules concerning the quality of environment in the Netherlands. It refers to the responsibilities of stakeholders such as central government, industries and general public when performing different activities that may harm the environment and cause negative impact to human health. Chapter 10 of the Environmental Management Act is dedicated to waste. The Act provides provisions regarding the planning of waste management activities, prevention and recovery of waste, as well as general

rules concerning management of household, industrial, hazardous waste, waste water and shipment of waste outside the country. The Environmental Management Act as mentioned above is a general act. In order to regulate specific areas such as WEEE, the act enables development of specific regulations such as the WEEE Management Regulations, which precedes the White and Brown Decree (Besluit verwijdering wit –en bruingoed, 01.06.1998). This decree lays down regulative measures regarding WEEE management, including actors & responsibilities for WEEE collection, treatment, recovery, finance, communication and reporting requirements. A central element of this regulation is the "Extended Producer Responsibility principle" which requires producers to establish a take-back scheme for WEEE. This includes the establishment of a collection and financing systems for the recovery and treatment of WEEE. Furthermore, producers are obliged to report to the government on compliance through a notification form. The WEEE Management Decree has been developed to regulate the use of certain hazardous substances in EEE.

Bellow a short overview of the main institution involved in WEEE policy implementation and enforcement is presented.

The Ministry of Infrastructure & the Environment (MI&E)

MI&E is the central governmental body responsible for transposing EU policies concerning the environment at national level. It consists of five directorates-general: The Environment, Mobility, Civil Aviation and Maritime Affairs, Spatial Planning and Water Affairs. The WEEE related issues are addressed by the directorate general the Environment.

The directorate general the Environment supports sustainable development and economic growth through sustainable use of natural resources, land, water, soil, air, and energy. The commitment is to maintain and improve the living environment, make it safe, healthy and clean for people today and for future generations. This involves managing the limited land and resources to meet competing demands in social and economic development for transport, housing, industry, agriculture and nature. In doing so, the directorate aims to safeguard and to sustainable integrate nature, landscape and culture heritage and to improve public safety. This involves horizontal cooperation with other directorates of the ministry such as Spatial Planning.

As the Netherlands is Member State of the EU, much of environmental policy in the Netherlands is based on EU legislation. In close cooperation with other EU Member States, the MI&E, including the directorate general the Environment contributes to international forums that tackle global issues requiring international cooperation, such as climate change, protecting biodiversity, sustainable use of natural resources, as well as WEEE. In this respect, the directorate works in close cooperation horizontally with other ministries. In doing so, it collaborated on such issues as: communication on international developments, support on EU level for various decision making processes, coordination and contribution on international policy development, international meetings and negotiations.

Inspectorate of Housing, Spatial Planning and the Environment (IHSPE)

The main responsibilities of the IHSPE are enforcement of laws, regulations and policy to ensure a safe, healthy and sustainable living environment. The tasks and responsibilities of the IHSPE are separated from provincial and municipal governments and other authorities with responsibilities for implementing environmental and spatial planning policy and regulations.

The IHSPE operates relatively independently of the MI&E in monitoring compliance of industry and commercial enterprises with environmental legislation and regulations. The IHSPE monitors risks to health and the environment from hazardous materials such as the use and disposal of asbestos, polychlorinated biphenyl and chlorofluorocarbons. The IHSPE may be called upon to investigate criminal offences when legal proceedings are instituted. In respect to WEEE, the IHSPE ensures that all EEE manufacturers registered in the Netherlands comply with the national legislation, are part of an official compliance scheme and that reporting is done accordingly.

The IHSPE cooperates in international enforcement of environmental law, particularly cross-border and international shipment of hazardous waste, including WEEE. There is an international hotline for reporting acute environmental incidents and other critical situations. Another area of cooperation is the harmonisation of laws and regulations, and the transfer of know-how on enforcement between EU Member States.

Provincial and local authorities

At the regional and local level, there are *provincial and municipal authorities* that are responsible for policy implementation, quality of the environment, including management of different waste streams within the boundaries of their territory. In accordance with the Environmental Management Act (Ch. 10, section 10.24): "in the interest of protecting the environment, the municipal council shall issue a waste ordinance ...(..)..which shall include rules on collection of household waste, transferring to another party.." This means that municipalities are responsible for collection of WEEE from households as one of the waste fractions coming from households.

IV RESULTS

The Results Chapter presents the results of the interviews and literature review with respect to the WEEE system and economical important metals management. The chapter is structured in 4 themes, namely Metals Flow in WEEE, WEEE Metals Processing and Recovery Technologies, WEEE Actors and Networks and WEEE Governance. Every theme address a particular component of the system based on the theoretical framework discussed in the conceptual framework (chapter II). The chapter provides for a comprehensive analysis of the current situation and identification of possible changes in the WEEE system with respect to better management of economical important metals.

Theme 1: Metals Flows in WEEE

Metals containing in EEE, are essential for the development of economic activities, manufacture of goods, services and infrastructure that supports our daily life. According to figure 5, the average metal content in a mobile phone is 23% and this represents the most important, valuable and of concern fraction.

Metals are indispensable elements for EEE manufacture, critical for certain functions and good performance of EEE. Indium is extensively applied in alloys manufacture for which has been called the "metal vitamin". An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals, thus very small amounts of indium can make big changes in an alloy. For example, very small amounts of indium are added to gold (Ag) and platinum (Pt) alloys to make them much harder and enable their application in EEE and dental materials applications. Antimony (Sb) in the form of antimony trioxide is extensively applied as flame retardants for plastic in various EEE. This application is very important due to safety and toxicity issues, especially after the 2004 ban of some extreme toxic organic flame retardants such as PCB (under the Basel convention). Antimony consumption is not expected to decline since no substitutions are available. Beryllium (Be) due to its mechanical and thermal properties relative to its low density, favourable electric conductivity, is a superior metal in comparison to other metals for EEE applications. Gallium (Ga) has good semi-conducting properties which make the metal important for production of integrated circuits which in turn are indispensable parts of high performance computers and telecommunication technologies. Tantalum (Ta) is a hard, tough and ductile metal, extraordinary resistant to corrosion against many organic and inorganic acids below 100°C. This makes the metal a very important raw material for performance of electrolytic capacitors applied in IT and telecommunications applications (EC, 2010).

Although very essential for the functioning of modern society, metals have become a subject of active discussions as their simple availability on demand, efficient application, recycling and overall life cycle management *per se* is not taking place for granted. In order to have a better understanding of metals applied in EEE, these are grouped into two separate divisions:

- *Metals of economical importance*
- Metals of environmental concern

The first group consists of a list of metals among which are: antimony (Sb), beryllium (Be), cobalt (Co), gallium (Ga), germanium (Ge), indium (In), niobium (Nb), platinum group metals (PGM), rare earth metals (REM), tantalum (Ta) and tungsten (W). The PGMs consists of ruthenium (Ru),

rhodium (*Rh*), palladium (*Pd*), osmium (*Os*), iridium (*Ir*) and platinum (*Pt*). The REM consists of 15 lanthanoids plus scandium and yttrium. These metals along with several other raw materials have been investigated by the EC Raw Material Initiative which produced a report on EU critical raw materials (EC, 2010). According to this report for a metal to be qualified as critical, the metal must "face high risk with regard to access, i.e. high supply risk or high environmental risk and be of high economic importance".

The second group consists of metals of environmental concern which application is regulated by the Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (the RoHS Directive). The directive refers to the following elements (substances): lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (Cr VI), polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs). According to the RoHS Directive, these substances application in EEE is prohibited or allowed in certain concentration beginning with 2006. For instance, HP began using display glass free of arsenic as of August 2010, had tightened restrictions on mercury and beryllium and removed mercury in backlighting from HP's entire notebook line. It also introduced new personal computing products free of brominated flame retardants (BFRs) and polyninyl chloride (PVC) and solder alloys free of lead (HP, 2011). Another example is Apple which manufactures EEE free of BFRs and other harmful toxins, light-emitting diode (LED) backlighting free of mercury and glass free of arsenic (Apple, 2011). Nevertheless, in certain cases where substitution is not technical and/or economical possible certain substances are still applied. Mercury, in line with the maximum allowed concentrations, is still applied in manufacture of liquid crystal display (LCD) panels which produce no light of their own and require an external lighting mechanism to be easily visible. On most displays, this consists of a cold cathode fluorescent lamp that is situated behind the LCD panel and which contains mercury (Philips Consumer Lifestyle, 2011, interview). Due to the presence of a legal framework which regulates the application of these metals in EEE applications as well as companies trend towards eliminating these metals, these will not fall under further investigation.

Based on the literature review and the results of the interviews, several bottlenecks have been identified for the metals of economical importance which are central to this study.

Geo-political-economical issues

Despite the fact that the EU still has valuable deposits and much under explored and unexplored geological potential, the exploration of these faces increased competition for different land uses and is required to take place in a highly regulated environment. Currently, the EU supplies only about 3% of the world production of economical important metals which are essential for EEE manufacture (EC, 2010). As a consequence, EU EEE manufacturing industries are highly dependent on imports for many raw materials which are increasingly affected by growing demand pressure from emerging economies and by increasing number of national policy measures that disrupt the normal operation of global markets. For instance indium, REMs (i.e. europium) are good examples of metals which are subject of the above mentioned matters (Philips Consumer Lifestyle, 2011). The production of many of these metals is concentrated in few countries, i.e. > 90% of REMs and antimony (Sb) and more than 75% of germanium (Ge) and wolfram (W) are produced in China, 90% of niobium (Nb) in Brazil and 77% of PGMs in South-Africa. High technological metals are often by-products of mining and processing of major industrial metals. Indium is a by-product if zinc (Zn) and lead (Pb) mining, which means that indium availability and production is largely determined by the availability and production of the main host metal. Several other metals are

coupled metals, such as the PGMs which occur and are mined always together. Most of these metals are the same range of metals which are applied in the manufacture of sustainable future technologies in renewable energy and automotive sector. For instance gallium is extensively applied in the manufacture of photovoltaic panels, REMs in wind turbines, lithium (*Li*) in batteries of electrical cars, PGMs are important catalyst for conventional cars. The metals characteristics, increasing national policy measures of the mining and producing countries as well as a range of economical issues create pressure on the investment climate concerning metals recovery and recycling operations.

Application of metals and product design

The majority of respondents which were interviewed in this study stressed the importance of two aspects of metals and product design, namely:

- Application of metals in product components
- Components assembly into final products

By application of metals in product components is meant, the amount, composition and complexity of metals mixtures that is needed to obtain certain functionality. Currently, economical important metals are applied in very dissipative and small amounts in EEE. This is the case of indium in flat panel screen (UNU, 2011, interview). This respectively affects the indium concentration in WEEE and thus indium end recovery. Further, the design of components metals mixtures is done taking the metals physical and chemical properties into consideration. The priority here is to achieve the desired functionality. Due to the nature of information, designers do not take the metallurgical properties of metals into consideration. This leads to a situation where metal mixtures with different metallurgical behaviour are formed which are more complex to processes (Inspyro, 2011, interview). The recovery of metals processes can be much facilitated if designers of EEE mixtures and alloys would be informed on metals metallurgical behaviour and the environmental profile of these (TU Berlin, 2011, interview). Further, the end recovery of metals could be also much facilitated if metals diversity would be reduced, these would be applied in simple compositions that can be treated with less energy demand (TU Delft, 2011, interview). The example of plastic as a material flow could be taken into consideration where due to difficulties in recycling and reuse, reduction of diversity of plastic types has been done (HPFS, 2011, interview). Additionally, the diversity and amount of materials, including metals which are applied for the manufacture of products needs to be recorded and available for recyclers and metal refineries (Remondis Argentia, Siso 2011, interviews). In the absence of this information "losses of metals can not be even identified in the first place" (Remondis Argentia, 2011, interview).

Components assembly into final products or product design is another critical stage that can significantly contribute to better materials, including metals management throughout entire life cycle. For instance designing products with environmental and/or disassembly consideration in mind (DfE, DfD) is a useful strategy that can be applied to varying extents to increase the future rates of materials and components recovery and reuse. According to the literature review and interviews, DfE is not applied in a consistent and prevalent manner in the product design. This is strongly connected to the fact that currently the EEE domain is missing a legal framework on design for environment with coherent guidance at product design level. This is complimented by the fact that EEE manufactures have no market incentive to apply the DfE as irrespective of the EEE design, all the equipment is subject to the same pre treatment process. Nevertheless, the plastic flow, once again, is a good example that has introduced changes in the sector in line with

the DfE thinking. Philips Consumer Lifestyle up-cycles plastic for the production of new EEE equipment. This contributed to several changes at the product design level with respect to the environment to take place. The up-cycling process required the introduction first of all of the DfE considerations, so that to facilitate the manual dismantling and extraction of parts, selection and marking of plastic components as well as usage of better quality plastic that could be up-cycled (Philips Consumer Lifestyle, 2011, interview). The case is a beautiful example where the application of the DfE brings additionally to environmental benefits, a range of economical benefits and company competitive advantages on the market by placing products in line with cradle to cradle principle⁶.

WEEE Collection

The ICT Milieu Foundation (CS) collects WEEE from municipality waste yards (MWYs) and retail shops. These cover most of the time WEEE originating from households but also WEEE from private companies. In 2010, the WEEE collected by the ICT MILIEU CS originated mostly from MWYs (Table 1).

Table 1: Distribution of collected quantities among municipalities, retail shops and business in 2010. Source: ICT MILIEU Monitor, 2011

	Origin	Quantities	Percentage
1	Municipalities	2036063000	98,95
2	Retail Shops	20799100	1.01
3	B2B	725500	0.04
	Total	2057587600	100

In 2010 a total of 20.6 million kilograms of used WEEE were collected and recycled (Figure 15). In 2009 this was 22.4 million kilograms, which represents a decrease of 8.0%. The decrease is attributed to two major factors. The first factor is the economical recession which led to less equipment being sold and thus less equipment being disposed. Second is the fact that the weight of the ICT equipment screens category has decreased. For instance, the foundation reports that, in comparison to 2009 the weight of screens decreased over 20% (ICT MILIEU Monitor, 2011). The category screens include the heavy cathode ray tube (CRT) screens as well as the lighter thin-film transistor (TFT) and liquid crystal display (LCD) screens. Because CRT screens are becoming outdated, year after year these are less encountered in the WEEE stream. This explains the decrease of the total WEEE weight.

From the composition point of view, ICT waste stream consists mostly of computers, printing equipment accessories, telecom and other small ICT waste equipment.

⁶ Cradle-to-cradle design provides a practical design framework for creating products and industrial systems in a positive relationship with ecological health and abundance, and long-term economic growth (Braungart et al, 2006)

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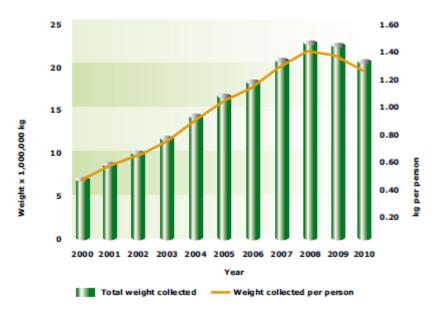


Figure 15: Amount of collected and recycled ICT equipment per year and per resident per year.

Source: ICT MILIEU Monitor 2011

In accordance with WEEE Directive, EU Member States are required to ensure a rate of separate collection of at least 4 kg/inh per year of WEEE from private households. The Netherlands ICT Milieu and Wecycle CSs are meeting this target and are even exceeding it. In 2010, ICT Milieu collected 20.6 million kilograms and Wecycle 106,3 million kilograms. In line with the Central Statistical Bureau, in 2010 there were 16574989 inhabitants in the Netherlands. This concludes that both foundations achieved a collection result of 7,6 kg of WEEE/inh. Both ICT MILIEU and Wecycle CSs collection results are good and exceed the requirements of the EU and national legislation. Nevertheless, these results are far bellow in comprehending the amount of WEEE which is generated by the Netherlands inhabitants which is about 18,5 kg/inh (Witteveen+Bos, 2008). In the light of the fact that much of the WEEE does not enter the official routes of the CSs as well as the fact that in 2008 the EC proposed during the WEEE Directive recast a new collection target of 65% as average quantity of equipment placed on the market in the two preceding years to enter into force from 2016, both foundations commissioned a study into the WEEE flow in the Netherlands. One of the concluding facts of the study was that the foundations manage to collect via their official route approximately only 1/3 of the total of WEEE generated which was 5,7 kg/inh out of 18,5 kg/inh collected in 2008 (Figure 16). This is explained in more details in the following subsection.

Although, the MWYs are responsible to collect the WEEE and hand it to the CS for further recycling there are still certain out flows which in 2008 counted for 14% from the total collected by these. The occurrence of these is mainly due to the tracking of products flow from the end consumer down to the recycling company and the role of the CS in these. Similar situation is with retail shops and various installers which collect WEEE privately. Their combined share in 2008 was 37,7%. In the current system, retailer shops collect the WEEE within the system "old for new" or in other words these are obliged to receive an old EEE when a similar new EEE is purchased. Beside product tracking issues as in the case of municipalities, an important element is that from consumer point of view, it is more convenient to bring the old mp3 player or any other small WEEE to discard it with a retail shop then with MWYs which some time may be located outside the city and difficult to find. Collection of WEEE would be much facilitated if retail shops would collect WEEE not on the basis "old for new" but "old for nothing" (Philips Consumer Lifestyle,

2011, interview). In the absence of convenient collection system, WEEE may turn to "hibernate" in households with no benefit.

Another example is the collection and recycling of metals by individual recycling companies which have a designed license for this activity. This is a legal activity that can be undertaken with no restrictions. Generally, according to field observations, most of the individual collectors recycle WEEE for such metals as iron, non ferrous copper and alumina additionally to recovery of large recyclable plastics and glass. The rest which is more difficult to treat is sent to incineration for energy recovery. This implies that most of the metals which although being economical important are lost as "a privet recycler will not send the clock of a washing machine to a metal refinery just because it contains economical valuable metals" (IHSPE, 2011, interview). Further, individual recyclers offer better price for WEEE as these do not have to treat the WEEE in line with the requirements of the WEEE Directive and thus will have less costs. Usually, high metal content equipment, particularly those which contain precious metals (gold, silver, platinum, etc) are subject to leakages as these can be traded individually with recycling companies.

Mixture of small WEEE such as old mobile phones, mp3 players with municipal waste is another important issue which accounted for 11% in 2008 from the total WEEE generated. This leads to first of all valuable resources being lost in streams from which it can not be recovered. This is the example of economical important metals which need sophisticated processes to be recovered. Second, small EEE discarded together with their batteries are sources of such metals as lead, cadmium and mercury which are known as "heavy metals" toxic for human health and dangerous under long term exposure. These metals act as contaminants of the municipal waste stream. If these enter an incineration plant, the stream will be contaminated and thus will affect the quality of the bottom ash which when cleaned can be applied as filling material by construction industries (TU Delft, 2011, interview).

The Netherlands has also various charity foundations and non-governmental organisations which collect ICT equipment for charity purposes and donations. ICT Milieu raised concern about these organisations, particularly on their legal status in collecting end of life EEE, the final destination of these and conditions under which these are recycled. This issue has been addressed with Siso which is a specialised company in the field of migration and replacement of depreciated ICT equipment including ICT development programs in third world countries. The company performs the latter activities with ViAfrica Foundation which supports social and commercial initiatives in Africa. In respondents opinions the problem with the ICT donation to Africa is that the donated equipment, which is inspected for functionality prior to donation, after being used can not be returned back to the EU for treatment. According to EU policies on waste, these can not be imported into EU for end of life treatment (Siso and ViAfrica, 2011, interview). This creates a situation where valuable resources due to local treatment conditions are lost and even more due to embodied hazard of certain metals cause danger to humans and create environmental pollution.

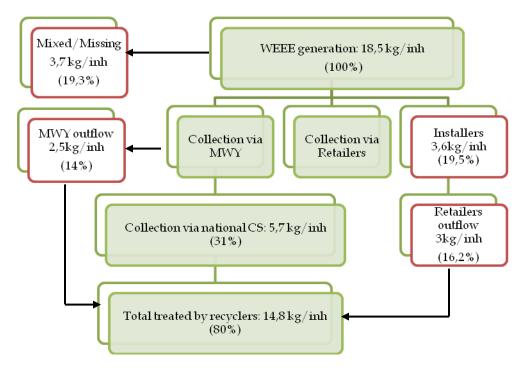


Figure 16: Complimentary flow in the Netherlands Source: NVMP interview October 2010

ICT MILIEU as well as Wecyle are highly aware of the situation and undertake various actions to address the complimentary flow. For instance, in order to reduce the amount of these, Wecycle and ICT MILIEU have signed a collection agreement with MWYs. The covenant states that MWYs have to hand in the collected WEEE solely with the official CSs. Further, the foundations organise various public awareness campaigns. Among these is introduction of "Jekko" which is a practical collection box for home use with separate compartments for small electrical appliances, broken lamps and batteries. Second, there is the RemixIT Initiative the aim of which is to collect small ICT via school pupils. Concerning the illegal export of WEEE as second hand goods, the foundations cooperates actively with Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (22 March, 1989), with Öko Institute, Germany and Ghana organization Green Advocacy on illegal export of e-waste from the ports of Antwerp and Amsterdam.

Provisional conclusion

Concluding on this theme, economical important metals are important ingredients for EEE as well as well for a range of innovative technological developments in renewable energy and automotive sectors. Their sound management during entire life cycle stages via metals efficient application, recovery and return into production systems has been recognised as essential. Economical important metals are subject to various geo-political and economical issues which create tension on development of metals recovery operations. Metal application in product components and their assembly has been identified as another major bottleneck in metals life cycle. Currently, EEE products incorporate only sporadically the DfE considerations. This consequently affects the rate of metals recovery and recycling from end products. Parallel to this, of greater importance the majority of respondents identified the collection of WEEE as one of the major bottlenecks in metals life cycle which affects many of the development in the end part of the product chain. Collection of WEEE is a challenging process as it incorporates the social component on which is largely

dependent on. Second, the collected amount is an important factor which affects the concentration of metals in metals refinery stage. This will be explained in greater details in the next theme.

Theme 2: WEEE Metals Processing and Recovery Technologies

This theme addresses the state of the WEEE technologies with respect to recovery and recycling of economical important metals. The theme presents and explains technological barriers which exist for complete recovery of metals from WEEE. The theme is dived into two subsections, WEEE preprocessing technologies and WEEE metals recovery technologies respectively.

WEEE Pre -Processing Technologies

The configuration of pre-processing technologies is a system configuration dependent on WEEE category to be treated. For instance cooling and freezing appliances my require installations for safe collection of ozone depleting substances, lamps and luminaries systems for absorption and isolation of mercury. A system configuration for treatment of ICT related equipment with its specifics is presented. The technology process is applied at Sims Recycling facility in Eindhoven, the Netherlands, which is one of the recycling companies working with the Netherlands ICT MILIEU CS⁷.

The ICT WEEE recycling is organized through manual and mechanical processing. At the initial stage batteries and copper are removed via manual sorting which can also occur at a later stage due to quality control and recovery of other non metallic materials. The equipment passes through a shredding machine which reduces materials to a size of approximate 100 mm. Materials are dropped into a shaking hopper so that they move evenly into a conveyer system. Then, materials pass through another size reduction which actually is done to facilitate and prepare materials for sorting. The dust which is extracted while materials are processed at this stage is sent to environmentally friendly disposal. Iron and steel (ferrous) are removed from the reduced materials by using electromagnets. The recovered materials are stored in large containers and are ready to be sold. Aluminum, copper, brass (non ferrous) metals are separated from materials with low or non metallic content such as wire, plastics and printed circuit boards. This is done by using 'eddy currents' separators created by rapidly alternating magnetic fields - which induce non ferrous to leap away from the conveyer, while others drops straight. The recovered non ferrous are stored in large containers and ready to be sold, while the rest is further processed. A process of water separation is used to float plastic and glass from printed circuit boards and copper wire. These are collected and are ready to be sold for further processing and economical important metals recovery.

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⁷ For more details, please visit www.simsrecycling.com.



96.5 % Recovery (84.3 % Material re-use) (12.2 % Energy recovery)

3.5 % Disposal

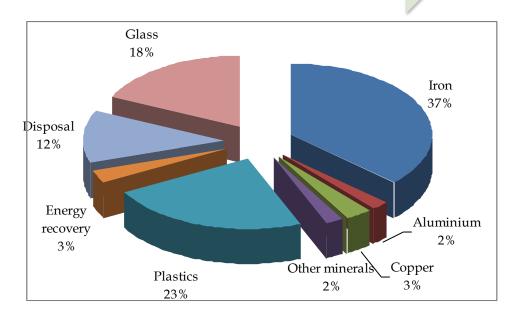


Figure 17: ICT MILIEU, Collected and Recycled output, 2010

According to WEEE Directive, Article 7, 7.2b and Annex IA Categories of electrical and electronic equipment, manufacturers of ICT related equipment falling under category 3 and 4 need to ensure a rate of recovery of minimum of 75 % by an average weight per appliance, and component, material and substance reuse and recycling of a minimum of 65 % by an average weight per appliance. ICT MILIEU recovery rate is 96, 5% and materials reuse 84, 3% which is very close to a closed recycling loop (Figure 17). Among these energy recovery is 12,2% and only 3,5% are materials which can not be reused and thus are disposed. Among recovered materials are iron, aluminium, copper, other metals, plastic and glass. The breakdown of recovered materials depends on the specific characteristic of the prevailing products with ferrous metals glass and plastic generally prevailing followed by non ferrous metals. These are recovered via the process descried above and are sold as secondary raw materials to other industries. Some materials, such as printed circuit boards are subsequently sent to smelters (i.e. Umicore, Belgium) where economical important metals are recovered.

Currently pre-treatment technologies are focused on removal of hazardous content as a priority and then on recovering as much as possible. In certain cases where end of life components have both hazardous and economical important metals, the choice is on safety removal of hazardous

content. Second, the focus is on quantity and not on quality (grade) of recovered materials and components. Economical important metals are usually located in fine components which need manual dismantling which implies higher treatment costs. In current circumstance, taking into consideration the end value of recovered of metals, certain losses of these occur.

WEEE Metals Recovery and Refining Technologies

As mentioned above printed circuit boards and other ferrous components in order to be treated need sophisticated installation that would allow recovery and refinery of metals. Umicore Group posses such installations, namely an integrated smelter, which is able to recover 17 metals among which are: Au, Ag, Pd, Pt, Rh, Ir, Ru, Cu, Pb, Ni, Sn, Bi, In, Se, Te, Sb, As (Figure 18). These metals are recovered from WEEE, catalysts and by products of non ferrous industries. The group of WEEE covers such equipment as printed circuit boards, multi-layer ceramic capacitors, mobile phones, MP3 players and digital cameras. The integrated smelter can treat up to 300000 t annually and is the world's largest facility for recycling of precious metals with a capacity of 50t for PGMs, 100t for gold and 2400 t for silver. The process is based on pyrometallurgy and hydrometallurgy with copper, nickel and lead as collector metals (Hagelüken, 2006). For most of the EEE materials the smelter is the first step. The smelter uses IsaSmelt submerged lance combustion technology and is equipped with extensive of gas emission control installation. At about 1200°C enriched air and fuel are injected through a lance in a liquid bath and coke is added for reduction of the metals. The precious metals dissolve in the copper while most other special metals are concentrated in the lead slag together with oxide compounds such as silica (Si) and alumina (Al). Next, the granulated copper obtained from the smelting is leached at the leach-electro-winning plant with sulphuric acid (H2SO4) resulting in a copper sulphate (CuSO4) solution and a precious metal-rich residue. The CuSO4 solution is send to electro-winning for recovery of the copper as 99.99% pure cathodes whereas the precious metals residue is further refined at the precious metals refinery. The refinery applies classical tradition methods in combination with in house innovations which allow for precious metal recovery with a purity of > 99.9. The lead oxide (PbO) slag from the smelter, containing lead, bismuth, nichel, indium, antimony, arsenic and some copper is further treated in the lead blast furnace together with lead containing raw materials. The blast furnace additionally to lead bullion produces copper matte which is returned back to the smelter, nickel speiss from which nickel is recovered and slag which is sold as a construction material. Last, the process applied by Umicore allows for substances of concern to be converted into useful products such as lead, antimony, arsenic and other as mercury, beryllium, cadmium to be captured and immobilized in an environmentally sound manner (Meskers et al., 2009).

Concerning the metals which are central to this study, gallium, ruthenium and indium, only the latter two are being recovered. Several factors influence the recovery and recycling of the metals. Among these are, but not exclusive:

- *Metal concentration in the WEEE stream*
- Metal price
- Metal metallurgical behaviour

Ruthenium and indium are metals which are largely influenced by these three variables in a positive way. Ruthenium, one of the PGM, is present in high concentration in the input (feed) of the metal refinery. This is because the input of the refinery consists also of other streams which have a considerable content of the metal. Ruthenium is a rare earth metal and this is reflected in

metal high price. Last, ruthenium dissolves in copper in the smelter and follows an analogue process as the other precious metals described above. Indium, due to extensive applications in EEE but also other applications as PVC, has also a constantly increasing price comparing to other metals. In the refinery process, the metal concentrates in the lead slag together with other oxide compounds from where it is further recovered. Although current technologies performance and metals extraction rate from WEEE leave room for improvement both metals worth the allocated costs associated with energy consumption per unit of recovery.

According to the Umicore processes currently gallium is not being recovered. This has very much to do with the factors presented above. First of all, gallium concentration in WEEE is low. Gallium price is also low in comparison to other economical important metals. This is partially linked to the fact that geological scarcity is not an issue for gallium and that there are vast bauxite reserves from which gallium could be extracted for many decades in the future. In order to understand the gallium behaviour in a metallurgical process, a virtual simulation was conducted together with Inspyro. The simulation consisted of the following: 1 gram of gallium, lead, silver and O2 where inserted into a smelter at 1000 °C t. The results of the simulation were that gallium being an oxide reacted first with the O2 and was the first to oxidise and transferred to slags. In the case of Umicore Plant, gallium from the smelter is transferred to lead slag which enters the Blast Furnace and from there gallium oxides again and is transferred to end slag (Ga oxides easily than Pb) (Figure 18). Thus, if gallium is to be recovered then it is from the slag of the blast furnace. Nevertheless, the amount of energy required to recover gallium from the blast furnace slag versus the metal concentration in slag and gallium market price leads to a situation where the economical input for the recovery of metal is not regained.

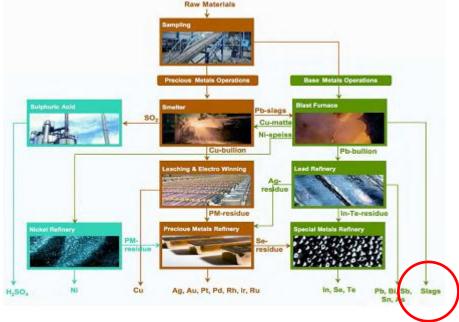


Figure 18: Umicore integrated smelting and refining operations (red circle the location of Ga). Source: Hageluken, 2007

Provisional conclusion

There are two stages in WEEE treatment, namely pre-treatment stage and metals recovery and refinery stage. Manual and mechanical processing as the main practice is applied for WEEE in the pre-treatment stage. Economical important metals require as much as possible manual dismantling so that to avoid economical important metals to be dispersed and enter streams from which it will

not be recovered. In certain cases, there is an environmental competing issue with the involvement of hazardous substances which have priority on safe removal at this stage. Further, manual dismantling is not performed as these would imply higher treatment cost with insufficient economical return. Therefore, losses of economical important metals do occur in this stage. Recovery of metals from components in the metal recovery and refinery stage is subject to a range of factors that influence and decide on whether the metal is recovered or not. The price of the metal is a factor which is the most influential and decisive one. This is the case for ruthenium and indium which do provide an economical incentive for metals recovery and refinery. At current gallium price, there are no feasible recovery processes available on large scale.

Theme 3: WEEE Actors and Networks

WEEE system can be described as a very complex system from the number and diversity of actors involved. This is related to the fact that the WEEE system extends and includes both the EEE manufacturers with its materials and components suppliers which form the upper part of the product chain and the WEEE collectors, recyclers and metals refineries which form the down part of the product chain. Currently, these two main parts of the chain remain separate, creating their own networks. Therefore, the present theme is divided around these two main networks.

EEE Manufactures and the EEE components suppliers

EEE manufacturers are very important group of actors taking into consideration that these are the actors behind the product initiation and manufacture. Large competitive EEE manufacturing companies strive to achieve competitiveness on the market by various means, including placing on the market products which are innovative, provide high performance to the consumer and are safe from environmental and health point of view. Thus, identification of suppliers of components and materials which will contribute to the creation of such EEE products and meet the demand of modern and innovative markets is important for them.

EEE manufacturing companies understand that in order to gain competitiveness they need to know their products materials composition, environmental profile and the costs involved. They perform extensive work on such issues as selection of materials, definition of materials mixtures, and identification of applications which are more efficient. Eco-efficiency is important for EEE manufacturers and is addressed via designing of products and components that use fewer materials and allow for incorporation, where feasible, of recycled materials into manufacture of new products. The identification of the metal origin is also very important as EEE manufacturing companies do not want metals originating from areas with conflicts and labour abuse, i.e. Tantalum from the Republic of Congo (EEE Company, 2011, interview). Together with the upstream suppliers they work on so called "Materials Declaration" which provide for full composition of EEE products and which can help the companies in environmental labelling processes (Philips Consumer Lifestyle, 2011, interview). EEE manufacturing companies need to know the safety profile of their products in order to comply with a range of product regulations, including RoHS. Companies may also restrict substances because of customer preference or because companies believe it is appropriate based on a precautionary approach. This involves the evaluation of substances of concern, assessing of alternative materials and safety trails. Increasingly companies together with their suppliers remove where technically and economically possible substances which are of concern and develop alternatives for such substances as arsenic, beryllium, mercury, BFR and PVC.

Beside these, competitive EEE manufacturing companies address together with their suppliers such issues as workers' rights, health and safety at the factory level. For instance EEE manufacturing companies get involved in such issues as development of standards for precarious work and job security, working relations, occupational health and safety, environmental issues in relation to working environment. This also includes conditions in which waste from production is managed, stored and hazardous substances and their waste are removed (IDH, 2011, interview). Inevitable, these will latter reflect in the company sales, performance on the market, corporate social responsibility image.

A good example of integration of both social and environmental requirements into their sourcing operations is the case of HP EEE Manufacturing Company, which launched in 2000 the Social and Environmental Responsibility Program (SER). The program aims to first of all help suppliers to build their own SER. This includes, developing of collaborative relations with governmental and non governmental organizations and industry peers. The issues company address range from suppliers' energy consumption, greenhouse gas emissions, materials selection and composition. HP communicates materials restrictions to their design teams and manufacturing suppliers through company General Specification for the Environment which is integrated into company product development process and into supplier contracts (HP, 2011).

The Compliance Schemes Network

The ICT MILIEU CS, as explained in the overview chapter (chapter III), is another important group of actors which from the EEE life cycle perspective is located in the down part of the EEE product chain. The compliance scheme is a foundation which has been created by EEE manufacturers which meet their obligations under the WEEE Directive collectively. Therefore, the main responsibility of the compliance scheme is to organise the end of life management of EEE on behalf of the EEE manufacturers.

The compliance scheme network consists of WEEE collectors, namely municipalities, retail shops, distribution centres, regional sorting centres as well as WEEE recyclers and metals recovery and refinery. The key position in this network belongs to ICT MILIEU CS. This cooperates with other members of the network on several issues. First of all, the CS together with other actors of the networks is involved in optimisation of costs associated with WEEE collection and storage, logistics and sorting at regional sorting centres. These costs in 2010 accounted for 72% from total allocated operational costs (ICT MILIEU Monitor, 2011). Second, the CS together with WEEE recyclers is working on extraction of most value from WEEE. This in turn will be reflected on the CS processing rate. Beside economical issues, the CS cooperates largely with WEEE collectors to raise awareness and mobilise society to discard WEEE appropriately. The CS is also part of the WEEE Forum which is a not-for-profit association of 39 WEEE compliance schemes in Europe⁸. The aim of the WEEE Forum is to provide a platform for these schemes to foster ideas and share best practices while optimising environmental performance through a proper management of WEEE. One of the activities is WELABEX which is the WEEE Forum's multi-annual project aimed at laying down a set of European standards with respect to collection, treatment, recovery and recycling of WEEE and monitoring the processing companies.

⁸ More information on WEEE Forum http://www.weee-forum.org/what-is-the-weee-forum

Due to its central place in this network, the CS is entitled with certain decision making power. For instance, the CS is in position to select recycling companies for treatment of WEEE. In doing so it can request for various environmental consideration as well as the availability of innovative methods for better treatment of WEEE and application of where possible disassembly. By tendering on this, the CS can directly stimulate the recycling companies to innovate on their process and other in house developments. Although performing well, the CS performance as such is bound and restricted to waste phase of the product. So far the cases when CSs have managed to promote changes in EEE design are limited. For instance in France, the national CS went to be more creative and to have managed to influence indirectly the design of the EEE. The CS charges an extra 10% of the fee companies which EEE contain BFRs, LCD screens which contain mercury and cooling appliance which contain HFC, substances contributing to global warming (EEE Company, 2011, interview). In the Netherlands, in current circumstances the CS remain to belong to the end part of the EEE product chain with no interaction with the upper part of the product chain.

Integrated chain cooperation for Environmental Reform in the WEEE

Practice shows that only via integrated cooperation along the chain, coherent and common efforts, sustainability practices can be introduced in the WEEE sector. A success factor for that is the presence and commitment of all relevant actors from the upper and down part of the EEE product chain. A good example in this respect is the activities of Philips in promotion of product with upcycled materials as in the case of plastic as material flow. In doing so the company cooperates with materials suppliers, WEEE collectors, materials processors and academia. The company understands that only by integrating all the life stages of the EEE, sustainability changes can be introduced and sustained (Philips Consumer Lifestyle, 2011, interview). The case could serve as an example for other materials flows, including economical important metals. Another good example is the Belgium Paper Chain Forum which coherently addresses the economic and environmental issues present in the paper industry. The forum brings together professionals of paper associations, namely pulp producers, paper and board producers, printing industry, paper recyclers and members of such organisations as Green Peace and Forest Stewardship Council (OVAM, 2011, interview).

As presented above in this sub section and in the case of Philips promoting environmentally friendly products, the EEE manufacturer can play a central role in engaging other actors to perform the environmental reform in the WEEE sector. This is particularly linked to the fact that "they work and affect the both sides of the EEE product chain" (IHSPE, 2011, interview). The EEE manufacturers are very effective in engaging materials and components suppliers by requiring these to change materials according to their environmental and safety profile. The nature of actions and decisions that are be undertaken by the EEE manufacturers affect to a large extend the nature of activities that are undertaken downstream by recycling and metals recovery companies. In certain conditions recycling companies need to adjust their processes and technologies to the specifics of the incoming WEEE flow. This is the case when these have to treat plastic containing BFRs, components containing mercury, such as switches or backlighting lamps and batteries which are subject to dedicated separated treatment. EEE manufacturers have been identified as actors which can introduce sustainable practices in consumer consumption patterns via environmentally friendly products (OVAM, 2011, interview). These have been recognised also to be able to play a better role in environmental communication. From the general consumer point of view, these comparing to any other party involved in EEE trading or WEEE collection can better engage the end consumer in environmental education, awareness and proper collection of WEEE (TU Berlin, 2011, interview).

Concerning the latter and the role of the consumer in the environmental reform in the WEEE sector, these have been addressed in the current research only at general level. The interviews which have been performed within this study included also answers which were given as from the general consumer point of view. According to these, consumers as an individual group of actors are an important and influential group of actors. Similar to EEE manufacturers, these can trigger changes in the upper and down part of the EEE product chain. For instance, consumers may show preferences for environmentally friendly goods and demand for removal of substances which are toxic and pose danger to humans and environment. This was the case for HP EEE manufacturing company to remove a range of toxic substances from its EEE products (HPFS, 2011, interview). Second, consumers are crucial for WEEE collection and may affect the performance of many actors involved in WEEE collection and recycling. The entire down part of the EEE product chain relays on the consumer discarding the WEEE with the designated collection points which latter will enter the recycling plants. In the current system, consumers receive awareness from the CS via various programs and educational campaigns. Nevertheless, the effectiveness of these is mirrored in the CS collection results which although in line with the national and EU legislation are much behind the WEEE generation rate. Further, the consumer as an independent actor group has not been investigated as these may imply a different type of data collection and analysis to which I refer more in details the introduction chapter, point 1.4 research scope and limitations.

Provisional conclusion

Based on the analysis of actor's cooperation along the EEE product chain, currently these are generally divided into two major networks. EEE manufacturing companies together with their material and component supplier form the first network. These cooperate mainly on selection of materials, components design and manufacture. The driving force for EEE manufacturers to cooperate is to increase their competitiveness on the market, improve the environmental profile of their products and build on their corporate social responsibility towards consumers. On the other end of the product chain is the CS with the WEEE recyclers and metals refineries which form the other network. These cooperate largely on issues of optimization of costs and increasing the value to be extracted from WEEE. Overall, the EEE manufacturers have been identified as actors that could play a central role in engaging other actors along the product chain to perform the environmental reform in the WEEE sector. This is explained by the fact that these are well positioned and can influence materials suppliers, design products which environmental considerations and show interest in end of life materials in order to return these back into production cycles. These are the actors that can stimulate and direct environmental flows towards integrated and sustainable life management. Nevertheless, this will only be possible when there is commitment from all other relevant actors along the EEE product chain with consumers playing nonetheless a vital role.

Theme 4: WEEE Metals Governance

This theme presents and elaborates on the WEEE Directive with respect to economical important metals and their future governance. The theme is dived into two sub-themes. The first sub-theme identifies and elaborates on the WEEE Directive bottlenecks in promoting efficient recovery and recycling of economical important metals. The second sub-theme introduces several considerations to be taken into consideration in selecting future instruments for sustainable and efficient governance of economical important metals from WEEE.

Drawbacks of the WEEE Directive

"The WEEE Directive is a classical waste directive" with emphasis placed on the concept of waste, the need of environmental and human protection (OVAM, 2011, interview). Since its development and enforcement in 2003, a range of variables that affect the WEEE as a waste flow have changed. For instance the consumption patterns and behaviour of regular consumers has changed. Currently, consumers show high purchasing interest in new high technological EEE which life cycle is shorter and shorter leading to the fact that replacement of these is done more often than before. This is driven by the developments in the EEE sector where production patterns are changing rapidly as well. Among these are the phase out of substances regulated by the RoHS Directive but also introduction of new technological metals which deliver better performance than the traditional base and precious metals. Second, waste is being interpreted more progressively as a resource as in the case of ICT WEEE which is seen as a potential source of economical important metals that EU is highly dependent on imports (IHSPE, 2011, interview). All these developments take place in an environment complimented by powerful metaphors such as "ecological footprint"9, "peak oil"10, energy and other commodity price signals, the 2008 economic and food crises and the latest "rare earth" which blend and contribute severally to a situation where resources are being continuously depleted (Backer, 2011).

"Legislation by default lags behind logically" (UNESCO-IHE, 2011, interview). This is also the case for the WEEE Directive with respect to recovery and recycling of economical important metals. This currently does not provide for an appropriate framework with respect to economical important metals which are applied in EEE manufacture. This is further complimented by several legislative bottlenecks that the WEEE Directive display, literature review and interview results:

• *Collection of WEEE*

According to the WEEE Directive "Member States shall ensure that by 31 December 2006 at the latest a rate of separate collection of at least four kilograms on average per inhabitant per year of WEEE from private households is achieved" (Article 5, the WEEE Directive). Taking into consideration the fact that for instance in the Netherlands, the average generation rate of WEEE per inhabitant is 18,5 kg, the WEEE Directive does not provide for a good balance between WEEE generation and collection target. The problem is planed to be attenuated with the WEEE Directive recast where an annual WEEE collection rate of 65% per Member State as from 2016 is proposed to be set, according to the average quantity of equipment placed on the market in the two preceding years (MI&E, IHSPE, 2011, interviews). Meeting the new target will depend much on the national CSs performance as well as the availability of market based instruments that could better engage the regular consumer. Currently, the WEEE Directive does not provide for any economical incentive for the regular consumer to participate in good WEEE collection. This leads to a situation where the EEE is hibernating in households and/or the consumer is more tempted by e-scrap dealers and EEE retail shops which give in exchange a certain amount of money for the old EEE (OVAM, 2011). The WEEE Directive although allocating responsibilities for sound WEEE collection, does not clarify coherently on the flow of WEEE from end consumer towards the treatment facility. For instance, the WEEE Directive does not stipulate that EEE retail shops, municipalities, other parties involved

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⁹ The ecological foot print is a resource accounting tool. It measures the area of productive land a country, a region of the world requires to produce the resources it consumes and to absorb its waste. According to the Global Footprint Network, humanity needed in 2007 the equivalent of 1,5 planets to regenerate the renewable resources and the CO2 sinks it needs for its overall consumption.

¹⁰ Peak oil is the point in time when the maximum rate if global petroleum extraction is reached, after which the rate of production enter terminal decline. According to the International Energy Agency, the production of convention of crude oil peaked in 2006.

in WEEE collection need to transfer the collected WEEE with the delegated CS. This leads to the fact that, there are large amount of complimentary flows which destination and treatment conditions are not all the time in line with the requirements of the WEEE Directive (UNESCO-IHE, 2011, interview). This point has been raised by the Netherlands government towards the EC in the frame of the WEEE Directive recast (MI&E, IHSPE, 2011, interviews). Finally, is the WEEE Directive allocation of products in group categories which is done taking into consideration the products use, application and not the treatment requirements and properties (TU Berlin, 2011, interview). Re consideration of products in line with their treatment and materials composition, i.e. mobile phones, PC, etc., would ensures that e-scrap is maintained in materials streams which are not contaminated and even alloys, alloys mixtures can be recovered and reused further as alloys for the same products manufacture (TU Delft, 2011, interview). These developments would also for instance be in line with the environmental principles of the IEC.

• Eco design and products recycling

Central to the WEEE Directive is the Extended Produce Responsibility mechanism which places EEE manufacture responsible for the EEE product when these enter the end of life stage. Linking the product manufacture to product disposal should act as driver for eco - design. This driver can be very effective in the case EEE manufacturers meet their responsibilities individually and thus responsible for their own end of life equipment. However, the WEEE Directive states that "Member States shall ensure that, by 13 August 2005, producers provide at least for the financing of the collection, treatment, recovery and environmentally sound disposal of WEEE from private households..... the producer can choose to fulfil this obligation either individually or by joining a collective scheme" (Article 8, the WEEE Directive). Under these circumstances, the link between the product design and end of life management is broken. Further, there are few economical incentives for the EEE manufacturers to apply eco-design as in the current WEEE system the equipment irrespective of the design enters the same treatment processing process (UNESCO-IHE, 2011, interview). This broken link also influences many decisions which are taken up stream in the EEE manufacture. In the case the EEE manufacture is interested in processing EEE for recovery of materials, components, EEE manufacture will look for the materials applied in the EEE manufacture on the first place. It will select materials which are better suitable for recycling, will likely reduce the diversity of materials and will implement a design which is easy for disassembly (Philips Consumer Lifestyle, 2011, interview).

Weight based recovery and recycling targets

The WEEE Directive requires that Member States ensure a certain targets for EEE recovery and material, components reuse and recycling. For instance in the case of WEEE falling under categories 3 and 4 of Annex IA this is "a rate of recovery shall be increased to a minimum of 75 % by an average weight per appliance, and component, material and substance reuse and recycling shall be increased to a minimum of 65 % by an average weight per appliance" (Article 7, 7.2b). This leads to the fact that, economical important metals, which are usually in applied in low and dissipative applications, do not fall under these targets and thus are continuously lost in treatment processes (TU Delft, 2011, interview). This is also complimented to the fact that, certain metals, although being economical important do not provide for an economical incentive for being recovered as "the importance, criticality of certain metals is not reflected in metals price" (TU Berlin, 2011, interview). Further, the Annex II of the WEEE Directive on Selective treatment for materials and components of waste electrical and electronic equipment is primarily addressed towards the treatment of components which contain substance which are regulated under the RoHS Directive.

The Directive 2009/125/EC establishing a framework for the setting of eco design requirements for energy-related products (the Eco Design Directive) does not provide a framework for the metals application either. The directive although establishing a framework for eco-design requirements for energy-related products is very much energy consumption oriented (OVAM, 2011, interview).

Concluding on these, the WEEE Directive does not incorporate any specifications on economical important metals which are applied in EEE manufacture and the existing provisions may be regarded to certain extend to be counterproductive. This is additionally complimented by the fact that there are no market based policy instruments to act upon a range of economical important metals.

Future governance and economical valuation of metals

Overall, the WEEE Directive could provide for certain future stipulations on economical important metals recovery and recycling. The WEEE Directive leaves room for these future stipulations (MI&E, 2011, interview). Changes may be introduced in the WEEE Directive categorisation of products, collection targets, the weight based recovery and recycling targets, stipulations on selective removal of components, etc., to differentiate among the EEE materials importance and criticality. Nevertheless, more studies need to be done to answer such question as whether the economical important metals need to be regulated as such on the first place, is the WEEE Directive the right instrument, which metals to include and which recovery targets, objectives to assign (OVAM, UNU, 2011, interviews). Additionally to the WEEE Directive, the Eco Design Directive may provide for a better environment to regulate the economical important metals and take into consideration the free movement of products within the market. Finally, regulations in the form of command and control may not even need it if there are sound and efficient market based policy instruments (Philips Consumer Lifestyle, OVAM, 2011, interviews).

"Market-based instruments are regulations that encourage behaviour through market signals rather than through explicit directives regarding pollution control levels or methods" (Stavins, 2003). The author refers these policy instruments as "harnessing market forces" because if they are well designed and implemented, they encourage firms and individuals to embark on pollution prevention and control efforts that are in their own interests and that collectively meet required policy goals. Market based policy instruments if properly designed and implemented allow environmental pollution alleviation to be realized at the lowest overall cost to society. These provide for the greatest reductions in pollution by those firms that can achieve these reductions most cheaply. In contrast, command-and-control approaches could as well achieve this cost-effective solution. Nevertheless, this would require that different standards be set, implemented and monitored. Market based instruments may create powerful incentives for companies to adopt cheaper and better technologies in respect to environment and resources. This is explained by the fact that market based instruments supported by the availability of efficient and cost competitive technologies will always pay off companies to go beyond in their internal processing and performing standards. Among the categories of existing market based instruments are charge systems, tradable permit systems, reduction of market frictions and subsidy systems. Charge system such as effluent charge, deposit refund system, tax differentiation is designed primarily to address and change the companies, individuals' behaviour towards the environment. Whereas user charges such as insurance premium taxes, sale taxes, administrative charges, tradable permit category are directed towards the environment as the main beneficiary. Governmental subsidies are considered the mirror image of the taxes and in theory provide incentives to address the environmental problems. In respect to WEEE system the importance of appropriate market based policy instruments has been raised by the majority of respondents of this study. "Hazardous metals are environmental problems whereas economical important metals, critical metals are economical problems which require market based instruments" (Philips Consumer Lifestyle, 2011, interview).

First of all the deposit refund system has been suggested as a possible instrument to address the fact that much of the WEEE does not enter the official routes of the CS and is hibernating on households (Inspyro, TU Delft, UNESCO-IHE, 2011, interviews). The instrument is a front-end deposit that may provide EEE manufacture with incentive to find substitutes, to recover and recycle the taxed materials as well as encourage consumer to bring the WEEE for the refund. The deposit refund system is largely applied on bottles in Germany where the main objective is to reduce the improper disposal and the materials (toxic) content of the products. Another example is the application of the system on lead batteries in US with the same objectives as in the case of bottles and where the system has proven to be self sufficient. Sweden applies the system on old vehicles. The product tax is another market based policy instrument that has been identified (Siso, Remondis Argentia, TU Berlin, 2011, interviews). "The beauty of this system is that manufacturers of EEE are able to incorporate any damage caused to the environment into the final cost of the product" (UNESCO-IHE, 2011, interview). Undeniable, this will lead to the fact that products may turn to be more expansive. Car industry is an example where this is already happening. This became cleaner and cleaner, more expansive as well, but after all it served and returned back to the whole community in the form of clean environment and clean air. Particularly, the product tax could incorporate the costs which are needed for sound recycling and recovery of materials, in our case economical important metals from WEEE. The need for governmental subsidies into the research to provide for development of cost effective technologies to be able to process WEEE and recover the economical important metals have been identified as essential (UNESCO-IHE, OVAM, 2011, interviews). Subsidising on studies on" how far the recycling concept can be pushed" is the only way to go forward in this respect (UNESCO-IHE, 2011, interviews). This is due to the fact that EU is not self sufficient in its own materials and thus investing in recycling via science represents an enormous benefit to EU economies, environment and employment. A negative example where this is not done is US which lead to a range of large industries becoming obsolete.

Product Service System (PSS) has been identified as a promising business model in comparison to the current models based on selling of the EEE. Theoretically, a model based on PSS has been recognized to be in line with such definitions as dematerialization, eco-efficiency and sustainable materials management. A PSS business model provides for better life cycle management of the product/material flows, both upwards and downwards in the supply chain, which can thus allow reduction of the major environmental impacts caused by these during the entire life cycle. Here the optimization of flows and innovation of processes emerge as an internal driver within the model and falls in line with the model actors (Philips Lightening, 2011, interview). When applied in practice, PSS may serve an excellent vehicle to enhance competitiveness and foster sustainability simultaneously.

Provisional conclusion

Currently, the WEEE Directive does not provide for a sound framework for the recovery and recycling of economical important metals. The WEE Directive provisions on WEEE collection, recovery and recycling targets have been identified counterproductive with respect to recovery and recycling of certain economical important metals. Moreover, there are no market based policy instruments with respect to a range of economical important metals to act upon. It is expected that the EU will perform more studies into economical important metals. The results of these will serve

as a background for future legislative developments. It is envisioned that this will be a mixture of policy instruments both from the WEEE as well as product domain. A holistic approach and the link between these, namely the WEEE and materials, metals realm regulations have been identified as central in this respect. Stricter regulations, in the form of command and control have not been identified as a way forward for the EU, especially in the case when regulations can not be monitored. On the contrary policy instruments based on market have been identified as instruments with strong potential to introduce sustainability practices in both production and consumption systems. These instruments will reward the EEE manufacture for applying metals efficiently, stimulate recyclers to recover metals and acquaint consumer with proper environmental behaviour.

V DISCUSSIONS

The chapter discusses the results of this research and the rations of the IEC and the EMT which have been selected as environmental theories to guide this study. Further, the chapter presents several emerging theories which may enhance the practical implementation of the environmental theories in practice. The chapter is structured around three issues, complexities in closing metals loops and the IEC system perspective tools, technology innovation and integration with management concepts, future governance of metals flows and the EMT.

Complexities in Closing Metals Loops

The IEC as described in the Theoretical Framework Chapter (Chapter II) provides for a comprehensive framework to analyse materials flows through industrial systems. It provides strategies, tools and guidance on principles according to which environmental flows need to be managed to satisfy current but also the needs of future generations (Erkman, 2001).

In the current situation the environmental flows which are discussed in this study, namely ruthenium, indium and gallium display partially a different situation in comparison to the provisions of the IEC. For instance, ruthenium and indium are metals which application and management throughout life cycle show many similarities in line with the IEC. Ruthenium rareness, important application in various economical sectors, high price, increased current demand but also forecast demand by emerging clean technologies lead to the fact that the metal is managed well through entire life cycle and in line with the short and long term of the IEC principles. This is particularly relevant for management of ruthenium from industrial process catalyst and glass industry where the metal is managed almost in closed loops. However, management of ruthenium from WEEE does not show these similarities. The recycling of ruthenium from WEEE is much lower and currently reaching a recycling rate of only 10%. The recycling of process tailings as well as of old scrap containing indium has been initiated recently due to metal importance and diverse application in alloys, solders and renewable energy technologies which also triggered an increase in indium price. The case of gallium goes beyond the management characteristics of these two metals as currently the metal is not recovered from WEEE. The metal occurs in very small concentration in natural ores but geological rareness and/or scarcity is not an issue.

Therefore, although the IEC provides for the required framework to achieve a sustainable and efficient short and long term management of metals, there are a range of dynamic factors that intervene with the principles of the IEC and that may influence the system outcome. For instance in the case of the studied metals from WEEE these dynamic factors are:

- short and long term metal demand of metals versus their supply;
- the application of metals in product components and mixtures;
- the design of the products that do or do not facilitate the recovery of metals;
- the willingness of consumers to participate in appropriate collection of WEEE;
- the availability of cost effective technologies to recover metals and technologies metals extraction rate;
- *metals prices*;
- other geo political and economical issues;

Additionally, these dynamic factors can vary in time, space and be interconnected with certain broader system parameters like economical recession. The align of existing practices to principles of the IEC in tandem with the dynamic factors that may influence and/or change the system outcome call for the use of the IEC system approach tools. Among these are life cycle analysis, mass balance calculations, input-output analysis and material flow analysis. These provide for constructive information concerning flows, impacts and sinks (Hinterberger et al., 1997). This information may be used by decisions makers in developing future strategies for sustainable management of environmental flows. Nevertheless, it is argued that the IEC tools have limitations with respect to varying dynamic factors and that the IEC may require for new approaches, designing of new tools, models that take these into considerations. These will ensure that the environmental aspects of the flows are addressed in tandem with other social and economical aspects, a main precondition for development of long term sustainable strategies and solutions. Structural economies provide for such an approach and calculation models.

Structural economics is a body of theory and methods relating changes in technology, life style and environment via a detailed and coherent story that extends over diverse lines of inquiry and formalization of quantitative evolution (Duchin, 1998). It aims to understand and help solve the important social and environmental challenges of current modern societies by broadening the scope pf the conventional economics and inviting cross disciplinary collaboration. Comparing to traditional economic framework, structural economics analyse systems in terms of their concrete and observable constituent parts as well as the interrelationship between these (Duchin, 1992). For example a constituent part of an economy is infrastructure which is analysed not only in terms of bricks and materials but also more abstract components such as technologies and social institutions. Structural economies take into consideration the qualitative aspects of the system, which most of the time are difficult to quantify but play a vital role in the system performance. It provides support to formulate the quantitative questions and latter to evaluate the results. Structural economics are about structural changes which imply that the constituent parts of the system are subject to changes in a dynamic environment contrary to a static one with the state of equilibrium as a basis (Pasinetti, 1993). The formal structural economics models are used to yield a set of possible solutions rather than a single optimal one. The major tool of the structural economies is the dynamic input-output model which take into consideration the various concrete (data basses, kg, EUR) and abstract factors (society behaviour, life style) that may influence the performance and outcome of the system. Over the paste decade considerable attention has been paid to these types of models and extending these input-output frameworks beyond the simple static and the accounting data base. The models have been broadened to be able to address the current complex environmental problems in a systematic and integrated fashion whereas the data base is no longer a matrix to accommodate the accounting data but also technical information.

The dynamic input-output model may have major contribution and implications for the IEC as well as development of new hybrid system assessment tools. It is obvious that the current management (i.e. recycling rate) of economical important metals may be improved only when the practices and the dynamic factors that affect the system performance are taken into consideration. The practice shows that there are major disturbances between the physical (metals) and economical systems. This calls for a shift from current practices towards another one or even towards a combination of several other more radical than current one. The dynamic input-output model may provide for combination and analysis of alternatives techniques and their interaction with economic systems as a valuable input for future decision making and policy development. Most of all, the information may be used for the development of various incentives schemes, identification

of bottlenecks in current practices and developments that will not be timely addressed by market. A fact identified in the case of certain economical important metals.

Technology Innovation and Integration as a Key to WEEE Reform

Technological innovation and integration are at the heart of both the IEC and EMT. Technology has been recognised as a powerful vector of global change but also as a factor of high inertia and environmental discourses (Grubler, 1999). Based on the elaborations in Conceptual Framework Chapter (Chapter II), the EMT calls for technologies evolution from end of pipe technologies towards preventive and clean production technologies and ultimately transit towards technologies integration with other elements of the socio-technological systems.

The purpose of the WEEE technologies is to ensure that WEEE is collected, the hazardous content is safely removed whereas useful content is as much as possible is recovered and reuse in new production processes. Concerning the evolutionary state of these technologies, various progresses have been achieved in the current WEEE system. According to figure 17 (Chapter IV, Results), the ICT recycling sector achieves a recovery rate of 96,5% which is almost a close loop and only 3,5% were disposed in 2010. Among the recovered materials were ferrous, non ferrous, glass, plastic which after being recovered can be applied in various manufacturing processes again. Nevertheless, the discourse of the EMT is drawn around the qualitative and not quantitative aspects of the processes and products. In practice, this implies a discussion about the quantity versus the grade (quality) of the recycling output. In practice, recycling companies have to find an optimum between the quantity and the grade which means decide on how much loss they are willing to have to achieve the desired quality of recycling output. This implies, the better the quality the more losses there are. Economical important metals which are applied in sophisticated components most of the time would require manual disassembly and not shredding which would imply higher costs and more losses in other streams which may be not as critical as the metals in inquiry. Due, to such factors as the design of the product, costs associated with processing, the availability of appropriate technologies and availability of market incentives. Currently the choice is still most of the time, where safely possible, in the favour of the quantity.

Second, as mentioned at the beginning of this sub-section is the technology contextual integration. This notion states that the focus should not be on individual technologies but on their functionality on the system level. This implies that technologies are to be integrated with management concepts such as new ownership relations, new prizing mechanisms, new roles of the state and the like. In practice, current technologies present along the EEE product chain remain to be implemented individually for their role in performing a certain specialised task. Integration of technology with various products, materials management concepts has been addressed so far by the EMT sporadically at a very general level. For instance the influence and the correlation between the products, materials new ownership models and technologies innovation is a domain that could bring many improvements in the current production and consumption systems. It is argued that a system based on functionality is considered to be beneficial both for the materials consumption, efficiency and general system and technology innovation (Stahel, 1997). Such systems can integrate all three aspects of sustainability: economic, environment and social (Mont, 2002), (Tukker, 2004), (Kang, 2008), again as a precondition for future sustainable development and development of sound solutions. For instance, offering the functionality of the products/materials implies that products are designed to last and be more durable. This would lead to fewer resources being extracted to produce goods which are also in line with the IEC dematerialisation concept and ecoefficiency principles. Changes in the product design may occur as these need to last, be suitable for

refurbishment and up-grade. A system based on functionality favours reuse of the entire product instead of the recycling which can be energy intensive and not provide for full recovery of materials. Due to the ownership of materials/products, system technological innovation will occur as these are linked to the economical interests of the products and materials owner. Nevertheless, the EMT remains very superficial at this compartment, leaving space for future explorations and development of needed notions.

From National towards Global Governance of Metals Flows

After almost four decades since its emergence, the EMT is currently regarded as one of the most coherent an integrated school of thought within the social science. The theory provides for a systematic theoretical framework for integrating social science and policy perspective on the way in which contemporary societies interact with their bio-physical environment (Spaargaren et al., 2009). The EMT is renown for the introduction of the ecological rationality, new modern forms of environmental governance, new modes of steering and market based instruments which are also know as "economising of ecology" and "ecologising of the economy" (Huber in Spaargaren et al., 2009) (Mol and Spaargaren, 1993) (Janicke, 1993).

Due to these varieties of new innovative concepts and theoretical notions aimed to modernize the thinking and interpretation of environmental problems, designing of solutions and required changes for the environmental reform to take place, the EMT has been selected as a central theoretical background for this study next to the IEC. Although being a strong environmental theory with remarkable practical examples in chemical industry, the reform in the WEEE sector is somehow lagging behind other sectors in the EU with respect to sustainability changes and implementation of environmental theories notions and prescriptions. First of all is the rationalization of the environment as an independent sphere in the WEEE sector. The environment as an independent component is well articulated in the WEEE Directive, where the protection of environment and humans are priority areas and are expressed via the directive itself, the extended producer responsibility to achieve WEEE collection and recycling targets. Nevertheless, so far the problem of economical important metals continues depletion is not addressed by the WEEE Directive, neither by other legislation at EU level. This may be partially explained by the fact that economical important metals are an emerging environmental problem with on going extensive research and therefore changes are to occur in the future. Second, the EMT argues for economical valuation of resources, internalization of externalities and the need for market based policy instruments. However, in practice, in the WEEE sector and especially with respect to economical important metals, these are scarcely developed. For instance, as presented in the Overview Chapter (Chapter III) every EEE which is placed on the market incorporates a fee for EEE collection and recycling. Nevertheless, the fee is calculated by not taking into consideration the range of dynamic factors which affect the recovery and recycling of economical important metals from WEEE. This leads to a situation where the fee fails to comprehensively recover the ever increasing diversity of economical important metals applied in EEE manufacture. The design of the product and metals application in components is another domain which could largely benefit from market based policy instruments as it is envisioned in the case of plastic flow from household appliances. The end consumer participation in WEEE collection is another important factor, as at present there are no coherent incentives for them to participate in appropriate WEEE collection and which is largely reflected in the WEEE complimentary flow. Market actors, for instance the interviewed EEE manufactures do show interest in environmental issues and corporate social responsibility is placed highly on the internal agenda of companies. In those cases where the majority of the actors of the chain are present and there is commitment, sustainability changes can be introduced and sustained overt the chain.

However, this may not be sustained when the chain is not completely represented. Further, the fact that economical important metals are mined in Asia applied in Asia, US, Japan, partially in the EU, consumed and recycled in the EU is another issue. This calls upon a multi actor, multi governance and multi country (global) approach to the governance of these metals.

Given the description of the current situation and the envisioning of the Environmental Reform in the WEEE Sector based on the EMT and IEC with respect to economical important metals, the governing framework is ought to be a creative, innovative and balanced one. However, the current system can be characterised as simple, imbalanced and very much individually focussed. It does not to take into consideration the fact the system is subject to such dynamic factors as the demand and the supply of the metal, design of the EEE (which does or does not incorporates DfD), consumer involvement in appropriate WEEE collection, cost efficient technologies, metals price, etc. Currently, the EMT at this chapter still has room for exploration and further development.

In doing so, the EMT may have stronger correlation with the sociology of networks and flows theory, which although still an emerging theory, provides for a new perspective and new modes for understanding the contemporary globalised world. This is particularly due to economical important metals looked upon as independent environmental flows which although being managed locally and nationally display high global characteristics. These are part of the global market, international trade, with global networks and powerful actors from mining and metals refinery plants, EEE manufacturing companies and the like. The sociology of networks and flows theory scholars argue that networks and flows operate in three spatial patterns or modalities, namely regions, global integrated networks and global fluids (Sheller and Urry, 2006). By regions modality is characterized actors and flows which are involved in fixed relationships, management practices which usually are bound and/or constrained to that region. This is the typical pattern of the pre-globalisation era. Global integrated networks can be described as actors and flows which also display stable and predictable relations and practices but these go beyond the established boundary of a certain regions. Further, this type of modalities delivers standardized quality of their products and flows with limited adaptation to local circumstances. Finally are global fluids which display opposite characteristic comparing to the previous one as these are flexible both in space and time. This configuration of flows in space is important as it induces different degrees of nation-states ability to intervene, regulate and ensure conditions for favourable interaction processes. Different governing patterns are likely to be characteristic for each modality. In his article Mol observes the biofules as a flow that emerge from regional spatial patterns to global one and that the way the environmental problems on sustainability and vulnerability are likely to be addressed in the future (Mol, 2007). He argues that future governance of these global flows will be based on harmonization and standardization of production patterns, labelling and certification and powerful large multinational companies as very influential actors in the governing and decision making process. Thus, investigation of the economical important metals from the perspective of sociology of networks and flows theory could bring valuable information on the directions both national and international governance on metals should take into consideration in order to ensure that there is coherence and balance between economical, environmental and social issues.

Concluding remarks on the chapter

Currently, the IEC and the EMT provide for comprehensive future directions that policy developers, industries and society at all can use as guidance to perform the environmental reform in the WEEE sector with respect to the economical important metals. In doing so, the identified regulatory and management bottlenecks along the economical important metals life cycle will need to be addressed timely and qualitatively. This will contribute to creation of the desired regulative environment and market playing field in line with waste=resources and even beyond these towards integrated management of recourses. Two emerging theories have been identified as complimentary to the IEC and the EMT. Structural economics with the dynamic input-output modelling may be useful for identification of alternative techniques as a valuable input for future decision making and development of various incentives schemes with respect to sustainable management of economical important metals from WEEE but also other sources. Technology integration with innovative management concepts has been identified to be able to accommodate economical, environmental and social aspects of economical important metals under one management horizon. Last but not least, the sociology of networks and flows theory may serve as complementary theory for development of coherent and sustainable governance practices with respect to economical important metals. Nevertheless, on the road to this efficient and sound management of economical important metals on local and regional (the EU) level is of principal importance to serve as a stable fundament for future global governing actions.

VI CONCLUSIONS

The chapter concludes on the main findings of the research with respect to governance of economical important metals flows from WEEE in the Netherlands. The chapter is structured in accordance with the research questions which have been set in the Introduction Chapter (point 1.3).

Bottlenecks in life cycle management of economical important metals and their relation with recovery and recycling of these from WEEE

Ruthenium, indium and gallium are economical important metals which are central to this study. These have been selected due to their high share in electronics sector. Three main bottlenecks have been identified in the life cycle of these metals which impact their recovery and recycling from WEEE. The majority of economical important metals are mined and produced by few countries in the world. These impose various export regulations which disturb the normal functioning of the market and create an unstable investment climate for metals recovery operations. Metals application in components and their assembly has been identified as another bottleneck which affects the recovery and recycling of metals from WEEE. Economical important metals are applied in dissipative form and in mixtures that do not take the metals metallurgical properties into consideration. Further, these components are assembled in EEE products with fewer considerations on environment, disassembly and future reuse. The collection of WEEE has been identified as one of the most important bottleneck in the life cycle of economical important metals. Currently, only 1/3 of WEEE generated is collected and recycled by the official designated organisation. The rest undergoes questionable treatment, reuse, legal and/or illegal export as second hand goods. The amount of WEEE which does enter the official route goes through partial disassembly and mainly mechanical treatment. The focus here is placed, where safely possible on recovering as much as possible, thus on quantity which is most of the time at the expanse of quality (grade) of the recovered stream. Further, economical important metals recovery and recycling from WEEE is strongly linked and affected by a range of dynamic factors which are originating outside the technological realm. Among these is the short and long term availability of metals on demand, the application of metals in product components and mixtures, the design of the products that do or do not facilitate the recovery of metals, the willingness of consumers to participate in appropriate collection of WEEE and metals prices.

These, complimented by other geo-political and economical issues around economical important metals affect the end life recovery of these and contribute to system vulnerability. Future performance of the WEEE system with respect to recovery and recycling of economical important metals will largely depend on the system comprehending these dynamic factors which are highly interconnected with each other and is largely dependent on.

The effectiveness of EU WEEE regulations in promoting efficient and sustainable recovery and recycling of economical important metals

The WEEE Directive together with the RoHS Directive has been investigated within the scope of this research. The major focus is placed on the first. The WEEE Directive is a classical waste directive which main objective is to ensure that WEEE is collected, the hazardous content is safely removed and disposed and that useful materials are recovered and returned back into production cycles. The current provisions of the WEEE Directive do not incorporate requirements on economical important metals recovery and recycling. Several drawbacks have been identified in the WEEE Directive that to certain extent are counterproductive for sound recovery and recycling of economical important metals. First is the WEEE Directive collection target. The WEEE Directive sets a collection target of 4kg/inh which is very insignificant comparing to the amount of WEEE generated. In these circumstances, much of the WEEE does not enter appropriate treatment and recycling which implies continuous loss of valuable resources. The WEEE Directive recovery and recycling targets is another major drawback with respect to economical important metals. The focus of these targets is placed on the weight and not on the importance of the metal. In these circumstances the decision is left upon the WEEE recyclers and metals refineries to recover or not the metal. The provision proves to work well on metals which provide an economical incentive to be recovered such as for ruthenium and indium, as for the other metals, such as gallium the market fails to provide sound recovery and return into production cycles. One of the major drawbacks of the WEEE Directive with respect to metals sound recovery and recycling is the WEEE Directive Extended Producer Responsibility mechanism. According to this, EEE manufacturers are responsible for the EEE product when these enter the end of life stage. The mechanism was introduced as a driver for eco - design implementation. In the situation where EEE manufacturers meet their responsibilities collectively, as in the majority cases in the EU, including the Netherlands, this driver has no meaning and the link between the upper part and the down part of the product chain is to certain extend broken. This creates a situation where EEE manufactures is not encouraged to implement the design for disassembly, design for metallurgy, etc., which respectively affects the recovery and recycling of economical important metals.

Market incentives on recovery and recycling of economical important metals from WEEE

Currently, the economical importance and criticality of a range of metals which are applied in EEE manufacture is not reflected in metals price. In such circumstances, there are market incentives for those metals, i.e. ruthenium and indium which have a high price and which creates a favourable market incentive for metals to be recovered and reused. This is not the case for metals which have low price. In such cases the market fails to ensure metals efficient recovery and reuse. Further, even

in cases where there is a market incentive for the recovery of the metal, the efficiency of these is influenced by the lack of complimentary incentives that could enhance the system performance. Due to current legal provisions interpretation, system arrangements, the broken link between the upper and down part of the EEE product chain, the EEE manufacturers has no incentive to apply the eco-design on EEE products. This means metals are applied in diminutive forms and in complex mixtures. This inevitable affects the economical important metals recovery and reuse. As such, EEE manufacturers at this moment have no incentive to cooperate with other actors along the product chain to recover these metals from end products. This can be partially explained by the fact that most of the EEE product components manufacture is performed outside the EU, whereas product assembly inside and the fact that electronics chains are very complex and large chains to work with. Finally, there are no incentives for end users to participate in appropriate WEEE collection with the designated organisations. This largely explains the dominance of the WEEE complimentary flow. The stated above implies that market incentives could play an important role in efficient and sustainable management of economical important metals through entire life cycle. Whereas the lack of these and/or any other regulatory provisions to act upon economical important metals, creates an environment where these are subject to continuous depletion.

Future interventions in EU strategies to improve the sustainability aspects of economical important metals recovery and recycling from WEEE

The results of this research show the significance of life cycle perspective when managing these economical important metals. Addressing such stages as metals application in components, product design, product stewardship with consideration on metals end recovery and recycling in a coherent and integrated manner may bring various improvements in the down part of the EEE product chain. Therefore, future interventions will need to bear a life cycle and integrated regulative approach. Due to economical important metals characteristics and various political and economical issues involved, the future instruments will need to be assorted, creative and coherent with each other as well as other sector policies.

In the current regulative system, the Eco-Design Directive and the WEEE Directive stand out as two directives that could potentially address the economical important metals.

The Eco-Design Directive may introduce certain provisions on economical important metals and EEE product eco-design. Certain guidance could be introduced on economical important metals application, efficient use and substitution. A bridge between the Eco-Design Directive and the WEEE Directive to support the implementation of eco-design needs to be created. In this respect the role of the certification schemes and EEE product labelling could be of important role. The instrument works on other environmental flows such as plastic and thus could be taken as an example to be applied for economical important metals as well.

ICT related WEEE is a valuable source of economical important metals. Development of waste-to-resource policies could significantly contribute to metals recovery, availability within the region, creation of employment and contribute to overall global environmental climate. The WEEE Directive displays several drawbacks with respect to economical important metals as transiting

from waste to resource. These are: insufficient WEEE collection, the focus on the weight of recovery and recycling targets as well as the broken link with EEE product eco-design. These need to be addressed on the first place. The WEEE Directive collection target is to be increased in the future, an issue discussed with the WEEE Directive recast. Nevertheless, better attention should be paid on how this new collection target will be met. The need to create financial incentives for the end user to participate in appropriate WEEE collection has been recognised as one of the main market incentives that could positively impact the recovery and recycling of economical important. Second is the allocation of responsibilities for the end of life management of EEE. These responsibilities need to be clarified and spread better among the stakeholders involved in WEEE collection. A smart and easy tracking system will need to be developed to monitor the WEEE flow so that to increase their transparency. Additionally, separate collection targets for small equipment such as mobile phones which are rich in economical important metals may be one point of departure with respect to better recovery of metals. This means that product categorisation of the WEEE Directive should be re-configured based on the product treatment characteristics and not the life usage purpose. A link of this new treatment category could be done with dedicated to product category recovery and recycling targets. This will ensure that a differentiation is made along the products containing materials and their importance. The Annex II of the WEEE Directive on selective treatment for materials and components of WEEE provides room where removal obligations of components containing high content of economical important metals could be introduced.

Concluding remarks on future governance of metals flows

Overall, current regulative environment provides room for future stipulations on economical important metals recovery and reuse. It is envisioned that future governing environment will embody a mix of policies and market based policy instruments, applied in a cooperative environment with industries, branch organisation, various knowledge platforms and society at all. Nevertheless, more studies need to be done to answer such question as whether the economical important metals need to be regulated as such on the first place, which regulation is the most suitable for this, what is the right instrument, which metals to include and which recovery targets, objectives to assign to.

VII RECOMMENDATIONS

Several recommendations are presented. These are meant to stress the importance of several issues which have been addressed in this research and could contribute to better recovery and recycling of economical important metals from WEEE. Potential actors which can take the lead in these developments are also presented.

- ➤ Mobilise end of life products which contain high content of economical important metals for proper collection. The research showed that currently this is one of the major bottlenecks the system is facing with. Various legal and organisational solutions have been proposed in this study and are planned in the future with the recast of the WEEE Directive. Nonetheless, until these long term potential solutions are developed and implemented, the national compliance scheme with its network could play a better role in this task. This can be done with the introduction of some regular campaigns with rewarding premium addressed towards the regular consumer at large. It is important to organise these campaigns with retail shops and other convenient collection points which would facilitate consumer discarding the end of life EEE. These could in longer term contribute and build the systematic behaviour of the consumer to discard the WEEE appropriately.
- Improve overall organisation, logistics and efficiency of recycling chains based on system approach. The present research showed the recovery and recycling of economical important metals is a system configuration which is subject to various dynamic factors of legal, economical, technical and organisational nature. In designing optimisation of recovery and recycling processes a system approach that takes these dynamic factors into consideration will need to be applied. Designing of future changes will have as a precondition that EEE manufacturers, WEEE Recyclers and the national/EU authorities come to a compromise and ensure that all aspects of sustainability are taken into consideration. Currently, the scientific literature from economical and environmental point of view provides for various tools to assess different configurations of the system that could lead to better recovery and recycling of economical important metals. Among these are dynamic input-output modelling, QWERTY/EE method, etc.
- ➤ Monitor and make transparent the WEEE flows. Currently as explained in this research substantial amount of WEEE enter complimentary flow with questionable destination and end of life treatment conditions. There is high need for transparency of WEEE flow from the manufacture door down to WEEE treatment facility. Development of smart tracking systems, for instance in the form of coding and/or assigning of a tracking number, may come to solve many of the problems the WEEE system is facing with. The role of designing this may fall with the EEE manufactures. Nevertheless, the implementation of these will be only possible if other actors of the EEE product chain support this development. This would also release much of the work performed currently by environmental inspection authorities in monitoring the WEEE flow within the EU but also exiting EU.
- ➤ Promote research on metals processing and end recovery technologies, especially for those metals which behave challenging in metallurgical processing. Continuous improvement of metals recovery rate will significantly contribute to metals end of life management. This task will lie down with academia and WEEE recyclers. Since these involve many economical risks, support form national/EU authorities will be essential.

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ANNEXES

	Name of the company/institution	Name of the respondent, position
	EEE companies	
1	Philips Consumer Lifestyle	Mr. Eelco Smit
2	Philips Lighting	Senior Manager Sustainability Mr. Thomas Marinelli
3	Hewlett-Packard Financial Services	Director WEEE Management Mr. Wesjo Heijkens
		HPFS Nijmegen general manager
4	EEE Company	
	WEEE Recyclers	
5	REMONDIS ARGENTIA B.V.	Paul van Oosterbos
		Remondis Argentia Moerdijk General manager
6	SiSo Computers B.V.	Ed Alting Siberg
	515 C C C C C C C C C C C C C C C C C C	General manager
	National Authorities	
7	Ministry of Infrastructure and the	Ms. Marlies Veenstra
	Environment	Directorate General The Environment Environmental Protection Office
		Direction Sustainable Production
0		Waste and Chain Management Unit
8	Inspectorate of Housing, Spatial Planning and the Environment	Mr. Carl Huijbregts Directorate of Operations
	Training and the Environment	Waste Shipment Regulation Program
9	Public Waste Agency for Flanders	
	Academia	
10	United Nations University	Mr. Jaco Huisman
	Ž	Scientific advisor, Institute for Sustainability
44	E 1 : 111 :	and Peace. Operational Unit Suitable S Cycle
11	Technical University Delft	Mr. Jan-Henk Welink Knowledge Platform for Systainable
		Knowledge Platform for Sustainable Materials Management
12	UNESCO-IHE Institute for Water	Mr. Maarten A. Siebel, PhD, MSc, PE
	Education	Associate Professor of Environmental
10	Dealin Hairennites of Technology	Biotechnology
13	Berlin University of Technology	Ms. Vera Susanne Rotter DrIng Professor for solid waste management,
		Institute of Environmental Technology
14	KU Leuven University, InsPyro	Ms. Els Nagels
	· · · · · · · · · · · · · · · · · · ·	Project Director

2. Interview schedule and the Questionnaire

INTERVIEW NR Authority/Company/Institution name Respondent name Contact address, email Date, location

INTERVIEW SHEDULE AND PLANNING

I Introduction of the research

1) Research theme, goal, research questions and proposed outcome

II A. Introduction of the visited authority/institution

- 2) In a multi level governing context, at which level and what is the role of your authority/institution in connection to WEEE (level: EU/national/local, role: policy development, implementation, enforcement)?
- 3) What are the responsibilities of your authority/institution in relation to WEEE?

II B. Introduction of the visited company

- 1) What is the company profile, company activities and world presence?
- 2) What is the company policy on Environment and particularly on WEEE?
- 3) What is the company policy on raw materials, metals management?
- 4) What are the company main drivers to act upon WEEE?
- 5) Are there any market or profit incentives in connection to WEEE?

III Questionnaire

The questions are presented in summarised version. Separate Questionnaire was developed for each category of institutions and companies under this study.

	Item	Questions List
I	Metals Flows	
1	Metals of concern	In my research, I focus on the following critical metals - <i>In</i> , <i>Ga</i> , <i>Ru</i> . I have selected them due to their: criticality on EU/global level, predominant share of use in electronics, current reduced recycling rate and under current conditions risk for future supply. Do you agree that these metals deserve most concern in WEEE flows or would you give priority to other material flow? Please explain your choise?
2	Metals life cycle	If you think of the lifecycle of economical important metals, from Mining to Recovery phase, which phases need to be addressed in order to reduce the impact on environment and improve metals management?

3	Bottlenecks in	What could be done, from your point of view, to cope with the bottlenecks in the		
	metals life cycle	above identified phases in order to improve the management of these metals?		
	EEE Companies	1) Does your company perform R&D to develop substitution?		
		2) Does you company takes "Design for Disassembly" into consideration		
		when developing new EEE?		
		3) Does you company takes "Design for Metallurgy" into consideration		
		when developing new EEE?		
4				
		depletion?		
		<u>1)</u> Raw Materials - Raw Material Taxes (is passed to the EEE producer);		
		<u>2)</u> <u>Products -</u> Eco Taxes, Green Certificates (is passed to the EEE producer);		
		<u>3)</u> Waste - Deposit Refund, EPR fee (both of which are passed to the		
		consumer);		
		<u>4</u>) <u>Selective collection</u> : Incineration Taxes, Disposal Taxes (are passed to the		
		EEE producer);		
		5) Secondary Raw Materials and Recycled Products - Tax Rebates;		
5	Metal cycles	What opportunities do you see in closing the material loops within the borders of		
J	within and	EU? What obstacles do you see in to closing the material loops within the borders		
	beyond EU	of EU?		
II	Technologies	of Ec.		
	2001110109100			
6	WEEE	To your knowledge, are there adequate technologies available, now or in the near		
	Disassembly and	future, for cost efficient recycling of economical important metals?		
	metals recovery			
7	WEEE System	What should be the main drivers in the WEEE sector to stimulate technological		
	Drivers	innovation?		
III	Actors and Networl	ks		
8	Actors	Which actors could bring sustainability practices into the electronics chain,		
		including in WEEE sector?		
9	Networks and	What could be done to strengthen the cooperation at the electronics chain level		
	cooperation	with respect to WEEE?		
IV	WEEE Policies	•		
10	WEEE Directive	What is your opinion on the WEEE directive? What are the implementation		
		problems with the WEEE directive?		
11	WEEE Directive	What could be done to address the implementation problems of the WEEE		
		directive?		
12	Extended Producer	What is your opinion of the EPR mechanism of the WEEE directive in addressing		
	Responsibility	some of the problems identified previously?		
**	(EPR)			
V	Future considerations			
13	Changes in the	What changes and at which level (EU/national) should be introduced to achieve		
	(W)EEE system	a more sustainable and efficient systems that treats its materials wisely? What		
	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	should be the main drivers for that?		
	ļ			
14	Future changes in	I What type of changes do you expect in the future governance of WEEE?		
14	Future changes in WEEE governance	What type of changes do you expect in the future governance of WEEE?		

